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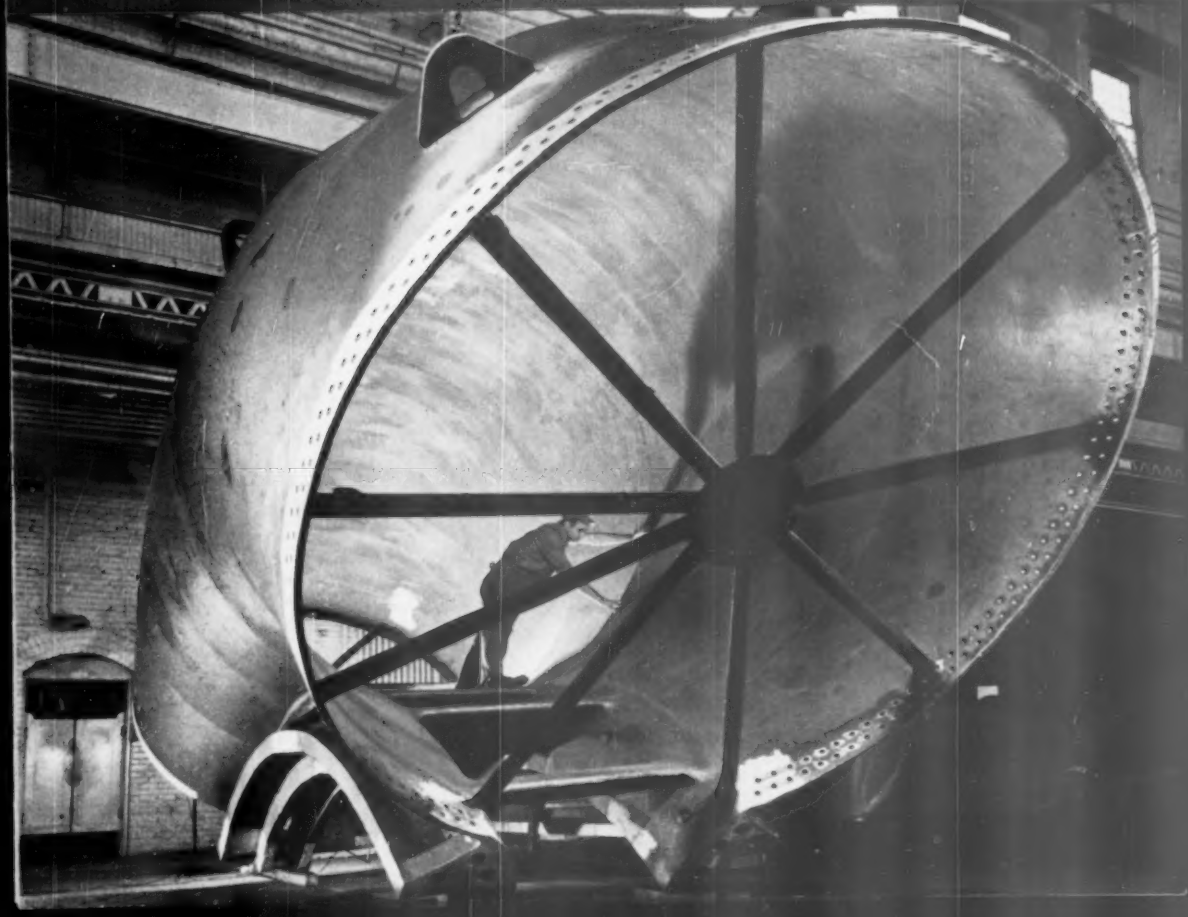
# WELDING JOURNAL

Official Publication of the American Welding Society



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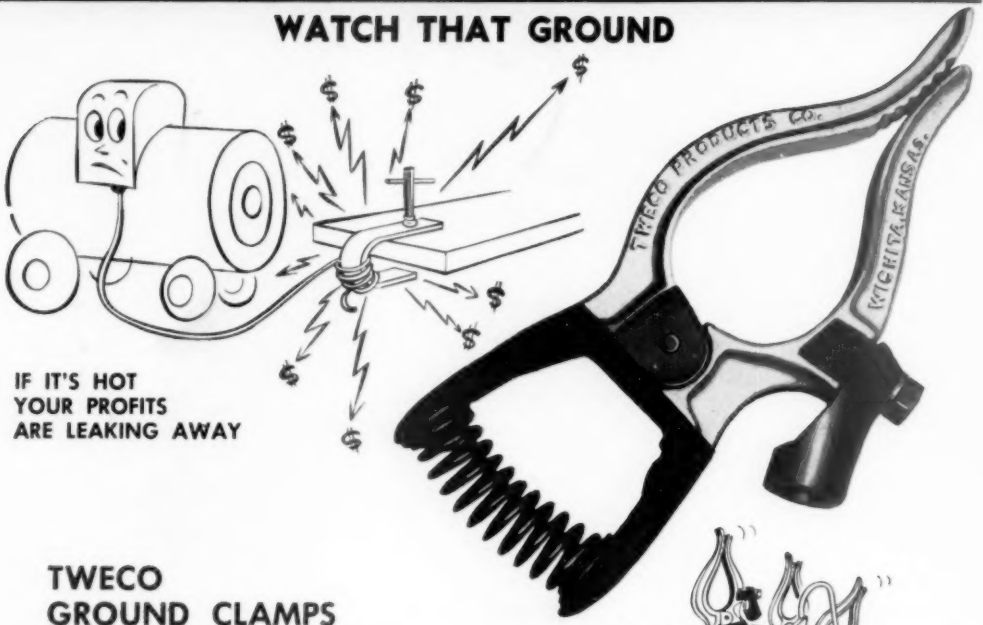


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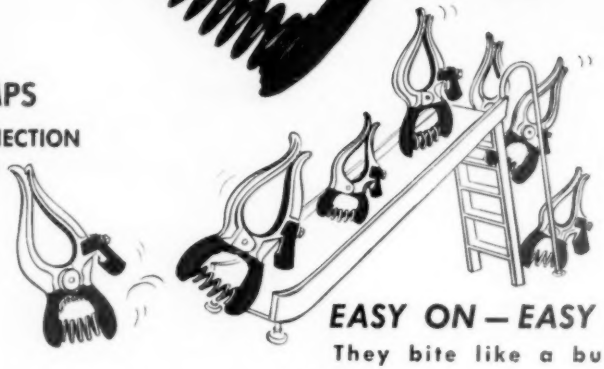

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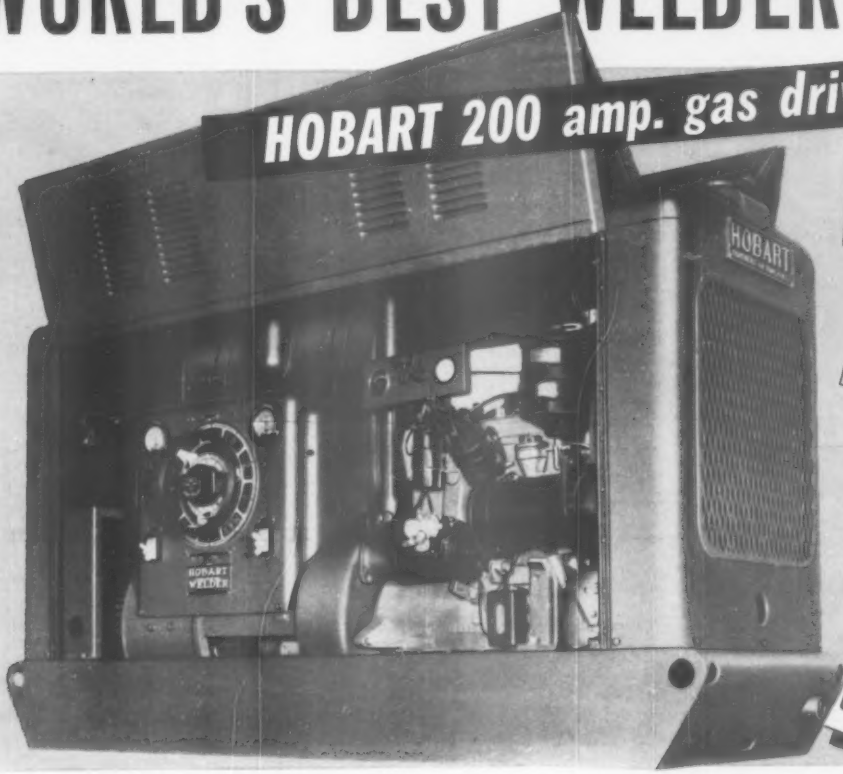


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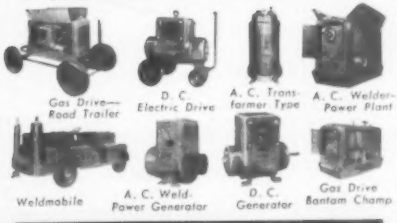


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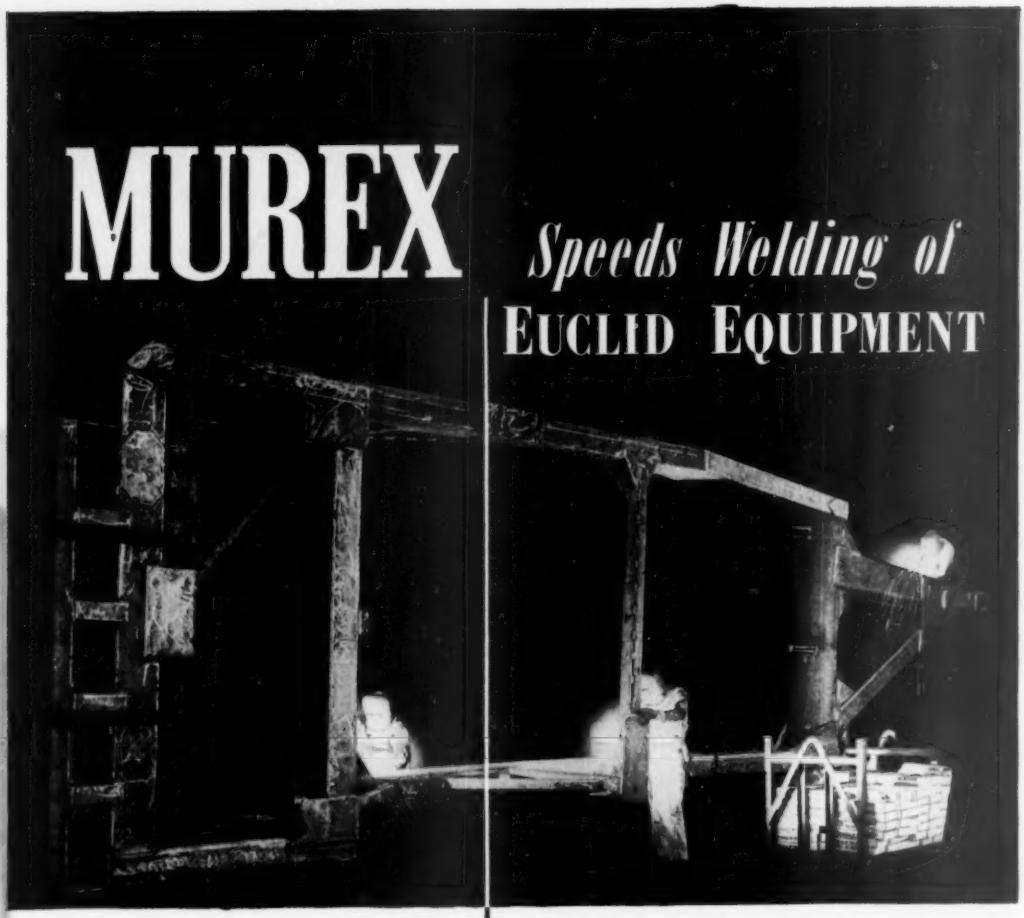

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The WELDING JOURNAL

volume 29 March 1950 number 3

# Application of Mild-Steel Electrodes

***The application of welding to code work limits the selection of electrode to that suitable for the specific code. In other instances greater freedom of choice is available. Fundamental elements governing choice are discussed***

*by F. R. Strate and R. I. Strough*

THE application of mild-steel arc-welding electrodes, since their introduction in this country around 1907 has become increasingly more complex as different types of mild-steel electrodes were developed by the electrode manufacturers to meet the demands of industry.

The first types of arc-welding electrodes used in this country were the bare wire or "fence wire" variety, the welding characteristics of which were improved by the addition of a thin "Sulcoat" or lime wash to the surface of the mild-steel core. These types of electrodes were relatively difficult to apply and produced weld deposits low in quality. Several of these bare-wire types of electrodes are in use today on applications where their "little or no slagging" characteristics are an advantage and where high quality of deposit is not demanded. These types of electrodes fall in the A.W.S. E4500 classification.

Industry's demand and the electrode designer's desire for improvements in the quality of the deposited weld metal brought about the development of the electrodes we know today as the A.W.S. E6010, E6012, E6020 and E6030 types of electrodes, plus the E6011 & E6013 types.

The E6010 types of electrodes attain their improvement in the quality of deposited weld metal over the bare-wire type mainly from the use of cellulose in the coating. The combustion of the cellulose in the arc produces carbon dioxide and carbon monoxide gases in sufficient quantity to envelop the arc stream and shield the transferring weld metal from harmful effects of the atmosphere. This type of coating lends itself readily to producing welds in all positions; also the weld metal exhibits high-average mechanical properties. The electrodes of this basic type operate on d.-c. reversed polarity (electrode positive) only and have deep penetration qualities and produce a rather flat bead.

The E6012 types of electrodes secured their improvement in the quality of deposited metal over the bare-wire type mainly from the use of rutile ($TiO_2$) in the coating. The rutile, in a sense, provided a physical shield for the transferring weld metal from electrode to work and produced a generous slag to cover the deposited weld metal. This type of electrode has somewhat less penetration than the E6010 type electrode along with a higher ultimate tensile strength and less ductility. It is characterized by a smooth convex bead and relatively low spatter and is usable in all positions of welding with d.-c. straight polarity or alternating-current power sources.

The E6020 and E6030 types of electrodes achieved their improvements in physical properties over the bare-wire types through the use of abundant quantities of mineral oxides in the coating which provided a physical shield for the arc transfer of weld metal and a heavy scavenging slag for the molten weld-metal pool. These types of

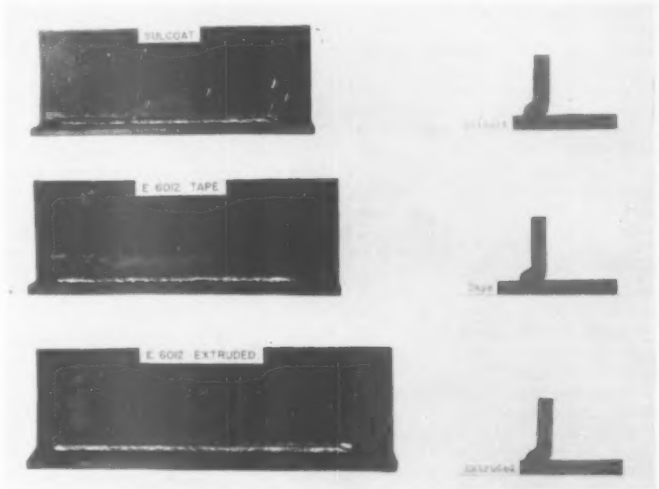


*Fig. 1 Evolution of the E6012 showing the progress from the Sulcoat through the tape type to the present extruded type*

**F. R. Strate** was formerly Welding Specialist, Air Reduction Sales Co., New York, N. Y., presently, President, Strate Welding Supply Co., Buffalo, N. Y. **R. I. Strough** is Welding Specialist, Arcrods Corp., Sparrows Point, Md.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

electrodes are characterized by a concave bead, deep penetration and high melting rates. The heavy slag produced by these electrodes limits them to applications in the flat position only. In general, these electrodes may be used with either straight or reversed polarity, depending on type of joint or application, or they may be used with an alternating-current power source.

Figure 1 pictures the story of advancement in the development of the E6012 class of welding electrodes. In each case 12 in. of the electrode was burned and a $^1/_4$-in. fillet weld produced, using $^5/_{32}$-in. diameter electrodes at the same machine setting. The Sulcoat electrode produced a porous convex bead 6.5 in. long. The 1932 version of the E6012 type electrode produced a convex bead 6.9 in. long. Incidentally this 1932 version of the E6012 electrode was manufactured by enveloping the core wire with an impregnated cotton tape—a process of manufacture too expensive to employ for today's market. The modern, extruded E6012 electrode produced a smooth flat bead 8.1 in. long, a gain of almost 30% in the length of weld bead obtainable with 12 in. of electrode over the Sulcoat type of electrode.

The E6013 classification of mild-steel arc-welding electrodes was the next general class of electrodes developed for industry. The development of this class of electrodes was brought about by the demand for a better electrode to use with the alternating current "transformers" that were coming on the market in the early 1930's. The E6012 electrodes on the market at that time were not wholly satisfactory for use with these early a.-c. welding transformers. Basically the E6013 class of electrode is a modification of the E6012 type electrode. Strong arc stabilizing agents such as potassium were used to accomplish this modification of improved operating characteristics on alternating current. The E6013 electrodes are characterized by smooth convex beads and low spatter. In general, the slag removal is easier than the E6012 class. The E6013 electrodes are usable on d.-c. straight polarity and in some cases are used with reversed polarity. They, of course, excel when compared to the E6012 class when using a.-c. transformers as the power source.

The E6011 class of electrodes was developed during the early 1940's and again the reason for their development was the demand for an electrode to operate on alternating current; however, there was an additional requirement for this development and that was the stipulation that the electrode meet the high-average mechanical properties of the E6010 class of electrode. In other words, the demand was for an E6010 electrode that would operate on alternating current. The designers of the E6011 class of electrodes approached the problem from varying viewpoints but in general the basic design

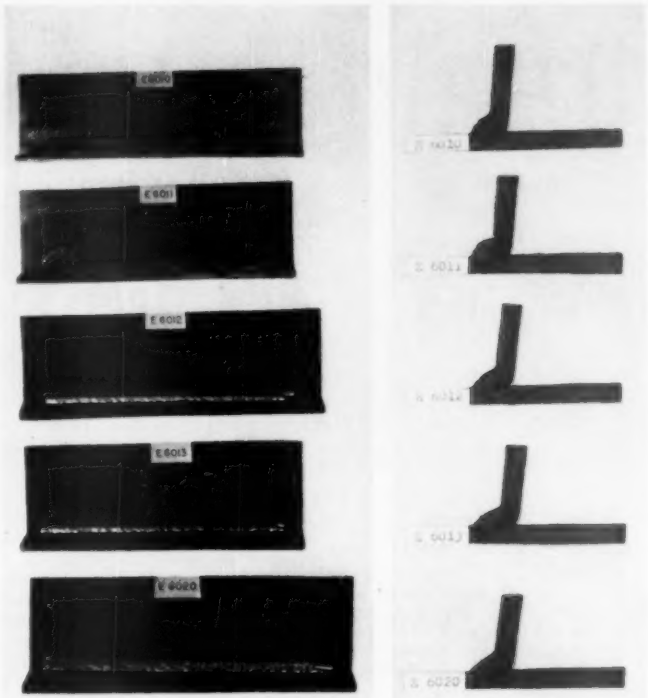


*Fig. 2 Comparison of the length of horizontal fillet welds produced by 12 in. of electrode of various A.W.S.-A.S.T.M. classifications*

was a modification of the E6010 electrode.

The E6011 class of electrodes are also usable with d.-c. reversed polarity and are similar in operating characteristics to the E6010 electrodes on d.-c. reversed polarity. These electrodes excel, of course, on a.-c. and produce the high-average mechanical properties demanded by industry.

Although the A.W.S. Classification series, E70XX, E80XX, E90XX and E100XX are not part of this discussion, it might be of interest to state that in general the development of these electrodes is accomplished by adding alloys to the basic E60XX series coatings. For example, the E7010 class of electrodes was developed by adding alloys to a basic E6010 coating, etc.

It may now be seen that considerations of application had but a minor influence in initiating and directing the development of the several classifications. Quality of deposited weld metal (mechanical properties and soundness) and the ability to perform satisfactorily with different types of welding power sources were the early prime factors. However, in the development of these several classes to meet the original demands of industry there inherently had to be differences in the operating characteristics of these electrodes which in the broad field of application might give one class of electrodes an advantage over another class on a specific type of application.

To illustrate pictorially the differences between the classifications of electrodes, several simple comparative tests on different types of applications were made.

**Table 1—Horizontal Fillets (Read with Fig. 2)**

| *Size of fillet, in.* | *Electrode* | *Diameter, in.* | *Amp.* | *Electrode used, in.* | *Weld, in.* | *Weld, in./min.* |
|---|---|---|---|---|---|---|
| $^1/_4$ | E6010 | $^5/_{32}$ | 175 | 12 | 8.2 | 6.2 |
| $^1/_4$ | E6011 | $^5/_{32}$ | 175 | 12 | 7.7 | 5.4 |
| $^1/_4$ | E6012 | $^5/_{32}$ | 210 | 12 | 8.1 | 6.9 |
| $^1/_4$ | E6013 | $^5/_{32}$ | 210 | 12 | 7.9 | 6.4 |
| $^1/_4$ | E6020 | $^5/_{32}$ | 210 | 12 | 8.7 | 8.4 |

In each comparison, only direct current was employed and a nominal current value for the class and diameter of the electrode used. E6010 and E6011 electrodes are normally used with lower current densities than the E6012, E6013, or E6020 type electrodes, which practice has been followed in making comparisons.

In the application of electrodes wherein speed in producing flat or horizontal fillet welds is of prime importance the E6020 or "hot rod" type of electrode is outstanding as indicated by both the data and Fig. 2.

However, it should be pointed out that if short welds are to be made wherein restriking of an E6020 electrode is required, the use of E6012 electrodes might be preferable if permissible under the applicable code or specifications. The E6020 electrodes, upon breaking the arc, produce a deep cup with coating extending beyond one core; this renders restarting difficult, hence the E6012 electrodes are preferred when this operation must be performed.

An interesting comparison of the characteristics inherent in the types of electrodes shows up when flat position lap welds are made. On horizontal fillets the E6020 electrode is unexcelled; however, in this comparison the E6020 electrode shows up very poorly. The poor showing of the E6020 electrode is due to the deep penetrating quality of the arc flowing more of the base plate into the weld than the fluid slag of the electrode can handle. Whereas the E6013 electrode with its lesser penetrating arc and quicker freezing slag shows up to better advantage on this particular application.

**Table 2—Flat Position Lap Welds (Read with Fig. 3)**

| *Plate thickness in.* | *Electrode* | *Diameter, in.* | *Amp.* | *Electrode used, in.* | *Weld, in.* | *Weld, in./min.* |
|---|---|---|---|---|---|---|
| 1/4 | E6010 | 5/32 | 200 | 12 | 10.6 | 8.7 |
| 1/4 | E6011 | 5/32 | 200 | 12 | 11.2 | 9.6 |
| 1/4 | E6012 | 5/32 | 200 | 12 | 10.9 | 9.5 |
| 1/4 | E6013 | 5/32 | 250 | 12 | 11.7 | 9.9 |
| 1/4 | E6020 | 5/32 | 250 | 12 | 9.4 | 8.9 |

Using the same type of joint as used in Fig. 3 but inclining the plate 15° from the flat it is found that entirely different sets of production figures turn up. The E6010 and E6011 electrode maintain the same rate of production. However, the production rate of the E6012, E6013 and E6020 electrodes jump an average of 27%.

The greatest jump in production rate is accomplished by the E6020 electrode where the fluid slag and deep penetration help to increase the inches of weld per minute.

E6020 electrodes were not included in this comparison because their fluid slag and deep penetration do not lend themselves to sheet metal applications.

The pictorial comparison of the four A.W.S. classifications shown in Fig. 5 indicates that the E6011 type electrode might be the most satisfactory type for this application because of its long length of weld. However, a study of the data presented shows the E6013 electrode to be the best from the standpoint of the highest inches per minute of welding speed.

In the actual field of application, there is a difference of opinion. Some welders prefer the E6012 or E6013 type electrodes whereas others prefer the E6010 and E6011. For consistent production of watertight joints the E6010 and E6011 classes seem to have the preference.

Figure 6 pictorially shows the E6012 electrode giving the highest production rate on this 1/4 in. vertically down lap weld. In the length of weld producible with 12 in. of electrode the E6011 electrode is next in rate, the E6013 electrode is second in the

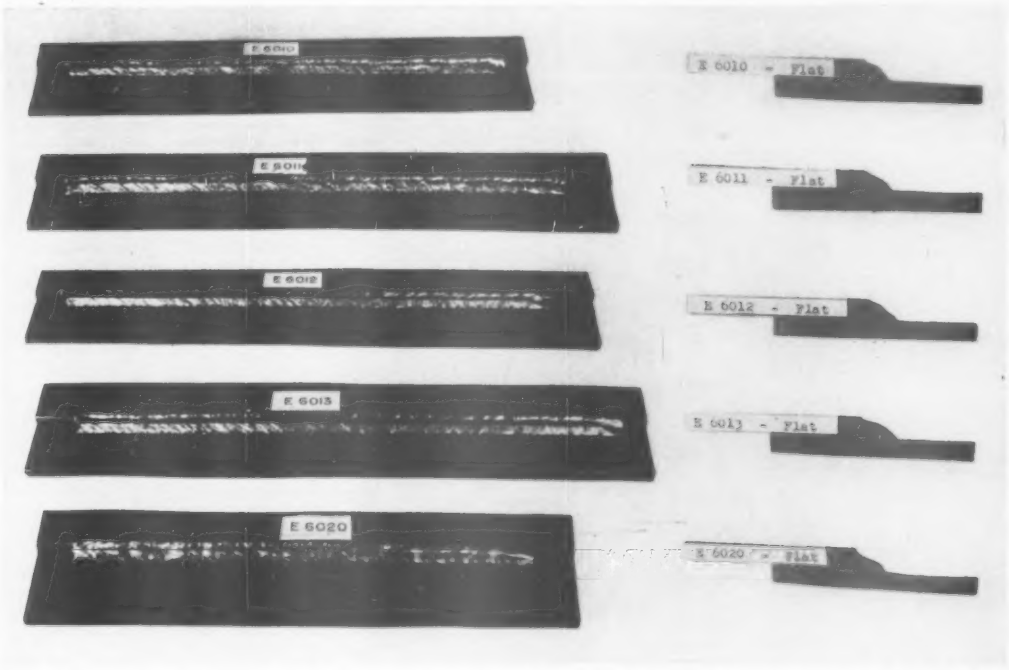


*Fig. 3 Comparison of the length of flat position lap welds produced by 12 in. of electrode of various A.W.S.-A.S.T.M. classifications*

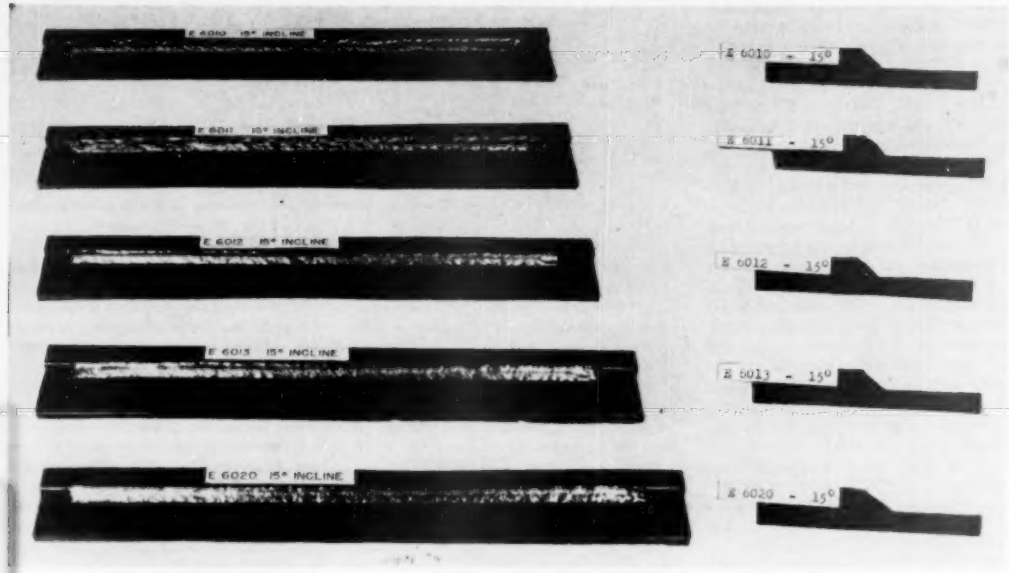


***Fig. 4 Comparison of the length of 15° inclined lap welds produced by 12 in. of electrode of various A.W.S.-A.S.T.M. classifications***

**Table 3—15° Inclined Lap Welds (Read with Fig. 4)**

| *Plate Thickness, in.* | *Electrode* | *Diameter, in.* | *Amp.* | *Electrode used, in.* | *Weld, in.* | *Weld, in./min.* |
|---|---|---|---|---|---|---|
| 1/4 | E6010 | 5/32 | 200 | 12 | 10.2 | 8.5 |
| 1/4 | E6011 | 5/32 | 200 | 12 | 11.2 | 9.3 |
| 1/4 | E6012 | 5/32 | 250 | 12 | 12.6 | 11.2 |
| 1/4 | E6013 | 5/32 | 250 | 12 | 13.0 | 10.9 |
| 1/4 | E6020 | 5/32 | 250 | 12 | 14.0 | 13.9 |

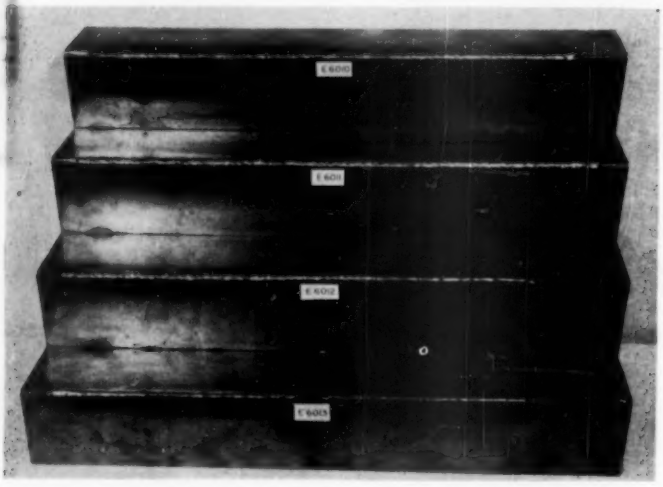


***Fig. 5 Comparison of length of corner welds produced by 12 in. of electrode of various A.W.S.-A.S.T.M. classifications***

number of inches of weld produced per minute.

Figure 7 is an illustration of the increase in the length of a 1/4-in. fillet obtainable as the diameter of the electrode is increased.

It is interesting to note that the 7/32 in. diameter, an electrode whose use is relatively low, gives approximately 30% more weld per 12 in. of electrode than does the 5/16 in. diameter. This fact lends itself to many applications, nation wide, where 5/16-in. diameter electrodes are being used where possibly 7/32 in. diameter could readily increase production. It has been the authors' experience that on many occasions attempting to increase production by increasing the diameter of electrode used have jumped from 5/16 in. diameter to 1/4 in. diameter and on finding 1/4 in. diameters too large for the job have reverted back to 5/16 in. instead of demanding that 7/32 in. diameter be tried on the particular application.

## SUMMARY

The process of selecting the proper electrode to accomplish a specific welding application may be divided first into two parts: (*a*) Code work and (*b*) Noncode work.

If the welding application is governed by specific code the selection of electrodes is limited to using the largest diameter possible and consistent with the Code and the power source available.

If, however, the welding application is not governed by Code the selection of the best electrode for the highest produc-

**Table 4—Corner Welds—Sheet Metal (Read with Fig. 5)**

| *Plate thickness, in.* | *Electrode* | *Diameter, in.* | *Amp.* | *Electrode used, in.* | *Weld, in.* | *Weld, in./min.* |
|---|---|---|---|---|---|---|
| 1/8 | E6010 | 1/8 | 90 | 12 | 17.7 | 12.8 |
| 1/8 | E6011 | 1/8 | 90 | 12 | 18.5 | 13.4 |
| 1/8 | E6012 | 1/8 | 110 | 12 | 16.5 | 14.3 |
| 1/8 | E6013 | 1/8 | 110 | 12 | 16.6 | 14.7 |

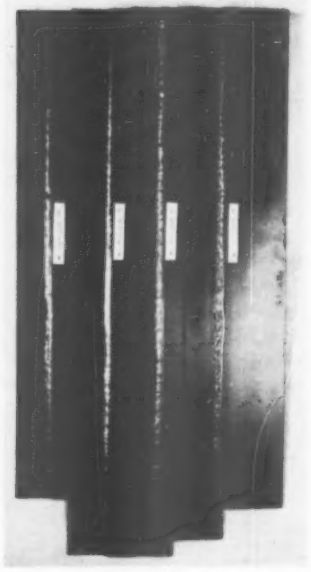

***Fig. 6 Comparison of length of lap welds made vertically down produced by 12 in. of electrode of various A.W.S.-A.S.T.M. classifications***

tion rate becomes a matter of the ingenuity of the welding supervisor and welder.

It should be axiomatic to the welding supervisor and welder that no one type of electrode will do every job best. A good illustration of this point is brought out in Figs. 2 and 3 where the E6020 electrode excelled all others on horizontal fillet welds, yet in Fig. 3 on a horizontal lap weld it was relatively unusable.

Some general points to keep in mind in the selection of electrodes for specific jobs might be:

1. Weld metal of the highest average mechanical properties are deposited by E6010, E6011, E6020 and E6030 electrodes. (E6015 and E6016 not discussed in this paper should also be included here.)

2. On applications where good fit-up is secured and it is possible to consume an entire electrode the E6020 and E6030 electrodes give the highest production rates.

3. On applications where poor fit-up occurs the E6010, E6011, E6012 and E6013 electrodes should be considered.

4. On applications where multipass welding is required on heavy sections E6020 electrodes may crack in the first pass; if such cracking occurs the use of E6010 or E6011 electrodes will eliminate the difficulty without preheat.

5. On applications where the plate material approaches the high side of weldable grade and E6020 or E6030 electrodes crack due to their deep penetrating characteristics the E6010, E6011, E6012 or E6013 electrodes may suffice.

6. On sheet metal applications where lap or corner joints are used E6010, E6011, E6012 and E6013 electrodes should all be considered.

**Table 5—Lap Welds—Vertically Down (Read with Fig. 6)**

| *Plate-thickness, in.* | *Electrode* | *Diameter, in.* | *Amp* | *Electrode used, n.* | *Length of weld, in.* | *Weld, in./min.* |
|---|---|---|---|---|---|---|
| 1/8 | E6010 | 5/32 | 140 | 12 | 21 | 16.7 |
| 1/8 | E6011 | 5/32 | 140 | 12 | 22.5 | 18.0 |
| 1/8 | E6012 | 5/32 | 175 | 12 | 23.5 | 22.2 |
| 1/8 | E6013 | 5/32 | 175 | 12 | 20.6 | 19.1 |

**Table 6—Horizontal Fillet Welds (Read with Fig. 7)**

| *Size of fillet, in.* | *Electrode* | *Diameter, in.* | *Electrode used, in.* | *Length of weld, in.* |
|---|---|---|---|---|
| 1/4 | E6012 | 5/32 | 12 | 7.9 |
| 1/4 | E6012 | 3/16 | 12 | 10.1 |
| 1/4 | E6012 | 7/32 | 12 | 13.5 |
| 1/4 | E6012 | 1/4 | 12 | 16.8 |

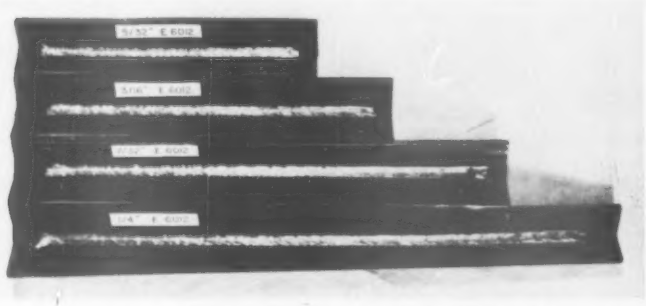


***Fig. 7 Comparison of length of horizontal fillet welds produced by 12 in. of electrode of various A.W.S.-A.S.T.M. classifications***

# Hardfacing Applications in the Steel Industry

***Hardfacing in the steel industry must be based on understanding of the nature of wearing conditions on the part and a corresponding understanding of the qualities and functions of the various types of hardfacing materials***

*by J. J. Barry*

FEW modern methods of general usefulness to all industry have been so fundamentally valuable to the steel industry as hardfacing, and few, if any, have stood the cold-blooded scrutiny of that industry so well. Originating in the oil fields, hardfacing quickly was taken up by steel mill maintenance men to solve numerous problems of wear on parts serving under almost unbelievably severe conditions. There can be little doubt that the steel industry is the toughest possible proving ground for a wear-resisting material, and the success and continued standard use of modern hardfacing methods in that industry is the strongest of testimony to their effectiveness. For in the steel mill, the alloy must do its job both in quality of results and in costs, or its place in the scheme of things is ended. Present steel industry economics do not permit the continued use of questionable or borderline methods—pennies and fractions of pennies are made to count in the cost of a ton of steel.

It seems, therefore, that the experience of the steel industry with hardfacing should provide valuable food for thought, not only for steel men themselves, but for all those who may be faced with problems of serious wear on parts subjected to impact, abrasion, corrosion, heat, erosion, or any combination of these factors. While hardfacing is not the answer to all of them, it is the answer to many, and while it is not always initially the cheapest method, it often is the least expensive in the long run. Such has been the experience of the steel industry, as well as many others.

One major factor in the success of the steel industry with hardfacing has been the understanding, gained from long experience, of the importance of the selection of the proper alloy for the specific job. Often a minor difference in conditions, between two apparently identical problems, permits the use of a far less expensive material with full satisfaction—or, conversely, requires the use of a far more costly alloy to do the job right.

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Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

The successful choice of a hardfacing alloy for a specific application requires two simple fundamentals:

1. Sound analysis of the nature of wearing conditions on the component.
2. Sound understanding of the qualities and functions of the various types of hardfacing materials.

Given this basis for selection, all that is required to assure maximum benefits is a welding operator to apply the material in the proper manner. Haphazard choice of materials is far more serious as a cause of hardfacing dissatisfaction and failure than is improper application—but the welding operation is also a vital factor in a good job.

## TYPES OF HARDFACING ALLOYS

The properties of modern hardfacing materials cover a wide range of variations, sometimes with almost indistinguishable graduations between various materials, from the harder and tougher materials among standard welding electrodes and rods, to solid inserts of tungsten carbide, and to wear-resistant materials that are scarcely "hard" at all, such as bronzes and brasses.

Hardfacing itself, however, is mostly concerned with the materials in three main groups, all of which may be generalized as harder and/or tougher than the base metal in question.

*Group I* includes the multitude of ferrous-base hardfacing alloys, which cover a major share of the applications.

*Group II* consists of the nonferrous metallic alloys, generally cobalt-base materials designed to provide hot-hardness for high temperature wear qualities.

*Group III* consists of the composite tungsten carbide types—ranging from fine particles to large solid inserts of carbide, in various matrices, for maximum abrasion resistance.

From this basic breakdown, it will be seen that Groups II and III are in the order of special-purpose classes, the one for hot-hardness and the other for extremely abrasive conditions. Less severe abrasion, most impact problems and problems involving both these factors, at normal operating temperatures, will usually be met with materials in Group I.

Metallurgical research has generally established that the constitution and structure of metals are fundamental factors that determine their properties. The science of metallography or physical metallurgy has developed around this recognition. Composition, as determined by chemical analysis, is important, and may be decisive in the production of a desired structure with its attendant properties, but other factors, such as heat treatment, may be more influential. It is also possible to produce a required structure with several different compositions, or to produce several structures by different treatments of the same alloy. For these reasons, it is usually desirable to consider hardfacing materials in terms of their structure whenever possible.

In soundly engineered commercial hardfacing materials, every effort has been made to produce an analysis which, by proper deposition and handling, will yield a microstructure as nearly as possible suited to the uses recommended for the alloy. In a paper presented last year at these meetings,[2] the fundamental microstructure of the more popular types of hardfacing materials was taken up in some detail, and this information is readily available. For the present purpose, however, we shall confine the discussion to the service conditions, as encountered in steel mill service, and the general types of material used to meet them.

## SERVICE CONDITIONS

The basic service problems of wear for which hard facing provides protection are:

1. Abrasion, or grinding friction.
2. Impact or battering.
3. Heat, often combined with 1, 2 or 4.
4. Corrosion, chemically, or erosion by hot gases.

It is seldom that we find a service problem which confines itself strictly to one of these conditions, although most problems have a single predominant factor.

It is only in meeting problems of pure abrasion that hardness itself is the most important characteristic of the hardfacing alloy. For this reason, where abrasion is most severe, the tungsten carbide materials are used. Such materials, however, do not provide much in the way of impact resistance, being so hard that they are quite brittle; and when we find appreciable impact involved with the abrasion, we must turn to a compromise material in the ferrous alloy range, which will provide an impact-resisting life measuring up to a good abrasion resistance. When the problem is further complicated by high-temperature service conditions, we must often go to the cobalt-base nonferrous alloys to find a material which provides a suitable balance of durability under all three conditions—heat, abrasion and impact. At times, the difficulties will be further complicated by erosive or corrosive conditions, but fortunately most of the heat-resistant materials are corrosion resistant as well.

[1] Avery, H. S. "Hard Surfacing by Fusion Welding" American Brake Shoe Co., New York, N. Y. (1947)

[2] Barry, J. J., and Muller, A. "The Economics of Hardfacing." THE WELDING JOURNAL, **28** (1), 31–37 (1949).

*Fig. 1 Straight-lipped clamshell bucket, one of many types of excavating equipment hardfaced for longer life*

*Fig. 2 Spindles and couplings, which take the hardest treatment of any machine parts, are an outstanding application of hardfacing in steel mills*

*Fig. 3 Rod-mill charging rolls, faced with a low-cost, air-hardening ferrous alloy, have much longer life than new parts*

Given such a range of possible service requirements, and such a range of possible overlays to resist them, it becomes apparent that we must take particular pains to select a hard-facing alloy for each particular job, to suit that job's needs. With that part of the problem, we must match up the economic requirements, and only a good measure of know-how and judgment will permit us to come up with the right answer.

Much of the difficulty, however, is resolved by the readily available breakdowns of analysis, microstructure and properties provided for the user of modern hardfacing materials. In most cases such information, coupled with a careful analysis of the problem, probably is enough to arrive at a sound answer. It is when we run up against the more complex problems that we must work out special individual answers, and often the job is a trial-and-error proposition.

It may be necessary to work out a suitable intermediate overlay between the base metal and the wear-resistant layer. It may be necessary to work out a heat treatment or cold-working method for the job. Preheating, cooling methods and other aspects of technique may prove the key to a more effective result. These elements, more than any fault in the material or its actual deposition, are likely to be the real reason for dissatisfaction and failure, and if the job is at all important, it is well worth while to make the effort to obtain top results.

Here again, the problem is often simplified by referring to the wealth of experience and know-how available through the manufacturer of the hardfacing material. With an accurate analysis of the job requirements and such factors as base metal analysis and structure, the technical information thus available can often either solve the problem outright or point the way definitely toward a wise solution.

*Fig. 4 Coke shutes, pounded and abraded by constant streams of coke, wear out quickly unless hardfaced with a suitable alloy*

*Fig. 5 Pickler crank, restored to size with a high-carbon material, will outlast a new part at a sizeable saving*

The service conditions in a steel mill exemplify more completely, than those of most industry the problems hardfacing is intended to alleviate or solve. And the manner in which the steel industry applies hardfacing materials to solve their problems illustrates some of the best, and most successful, practice in the field.

## APPLICATIONS

An outstanding and well-known success of hardfacing, not only in steel mills but in construction and other industries, is its use on bucket lips and other excavating and material-handling equipment. The ore-handling bucket, illustrated in Fig. 1, is one type of application in this class, one where service conditions consist of both abrasion and impact. For such an application, as illustrated in Fig. 1, a low-alloy ferrous material, yielding an analysis of approximately 0.85 C, 5.0 Cr, 0.90 Mn and 0.55 Si, and a hardness of Rockwell C 53–57 has proved an advantageous electrode. A similar material, in rod form, varies slightly in alloy

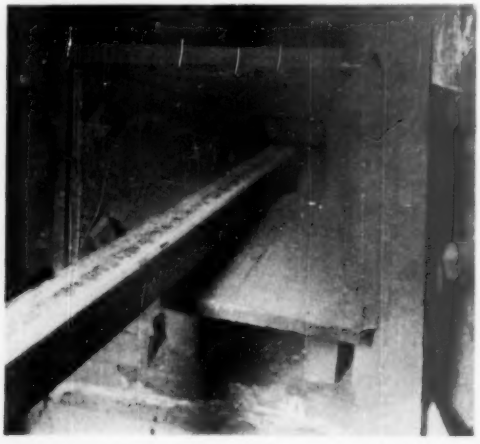

*Fig. 6 The guide to the charging rolls of a rod mill, serving under both impact and abrasion, is hardfaced at the exit end*

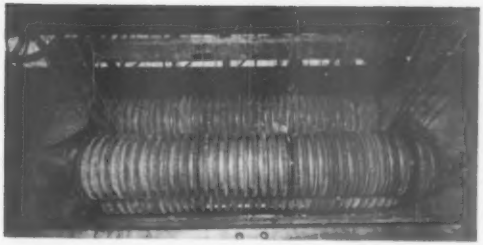

*Fig. 7 Scale breaker rolls are hard faced with a material which gives a life approximating that of normal shutdown periods, to reduce downtime and special shutdowns to a minimum*

content, but delivers similar combination of unusual toughness for impact resistance and high hardness for abrasion resistance. Smooth deposits, minimizing finish grinding when required, characterize both materials.

In other cases, particularly where the original bucket is of manganese steel, a nickel-manganese electrode is used to provide even higher impact resistance—at, of course, some sacrifice of abrasion life. These deposits, however, have excellent initial toughness, and good initial hardness which increases by work-hardening during use to Rockwell C 45 or better.

Another application of the low-alloy ferrous material, first described above for bucket lips, is on such parts as rolling mill spindles and couplings, as illustrated in Fig. 2. The service conditions for such parts include severe and constantly repeated impact as well as a rolling abrasion, and this air-hardening alloy steel has proved highly satisfactory in such service.

Figure 3 illustrates still another application of this material on rod mill billet charging rolls. These rolls are subject to a complex group of variable conditions—heat, impact and abrasion—and requires a "compromise" material which can provide good all-around properties for such variable requirements. The air-hardening type of alloy has provided one satisfactory answer to the problem in steel mill service.

Figure 4 represents a more normal type of use of this alloy—in the kind of service for which it is specifically intended. The coke-chute illustrated combines severe abrasion with severe impact and the plates wear out very quickly unless hardfaced. With the low-alloy, hardfacing material combining exceptional qualities of toughness and hardness, wear is sharply reduced and the life of the chute greatly extended.

Similar results with this alloy are achieved in the cases illustrated in Figs. 5, 6 and 7. Figure 5, a 4 in. diameter pickler crank, is faced with the arc and ground to a finish. Figure 6 a charging roll guide for a rod mill, is faced at the exit end to reduce the wear from both impact and abrasion.

Figure 7, however, is a case where there is an added factor introduced in the thinking behind the application. The air-hardening type of material is not the longest-lived alloy which could be used on these wire-mill scale-breaker rolls. It is a less expensive alloy, however, and provides a service life which approximates the normal shut-down period of the mill. In such a case, it is more economical to use the lower-cost, shorter-lived material and make replacements during normal periodic shutdowns than to use the more expensive material with longer life and either increase the required shutdowns for replacements or waste a sizeable part of the cost invested in the longer and unnecessary period of usability. This logic is an invaluable part of the savings obtained with hardfacing materials, for one of their greatest contributions, in cost cutting, is the reduction or elimination of repairs and downtime. On steel-mill equipment where periodic downtime is a regular necessity, the cheaper alloys can often be used in this way to extend the life of a part so it fits the routine repair schedule.

Figure 8 illustrates a type of use where different hardfacing alloys have been used for similar parts. These ingot stripper bits, as illustrated, are hardfaced with a high-carbon (0.60% as deposited) steel for low-cost wear resistance. These same bits, however

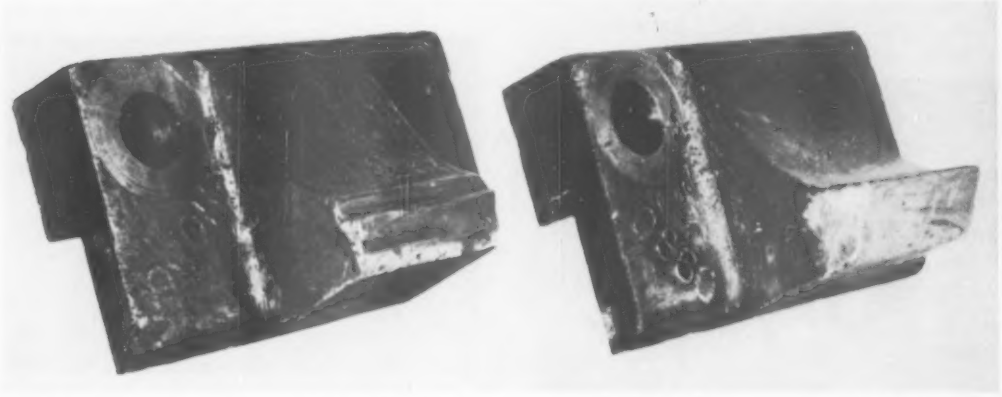

*Fig. 8 Ingot stripper bits, shown as hard faced with high-carbon material for "cold" service, may be similarly faced with cobalt-base material for greatly extended "hot" service life*

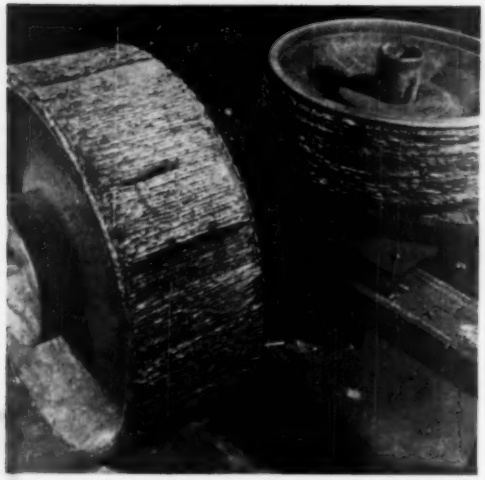

*Fig. 9 Use of high-carbon material on these crane brake wheels extends their life and permits a machined finish*

would require a high-alloy cobalt-base rod for good service life. Such bits, which without hardfacing have a service life of only a few hours, have proved to last an average of 80 to 85 hr. when hardfaced with such an alloy. In one case, where 600 such bits have been used per month, hardfacing with the cobalt-base, heat-resisting alloy cut the consumption to 50–60 bits per month—a 90% saving in bits, in the time required for replacing them and in lost production—and in spite of the cost of the alloy and its application, an appreciable dollars and cents saving resulted.

Where wear resistance is required, and machinability must be provided, the medium and high-carbon steels provide a good solution. As illustrated in Fig. 9, showing its application to crane brake wheels of various diameters, this type of material provides good wearing qualities on parts where moderate abrasion conditions exist, and the welds are machinable to a satisfactory degree.

The application of high-carbon materials illustrated in Figs. 10 and 11 combines both a building up and a hardfacing operation. The high-carbon electrode

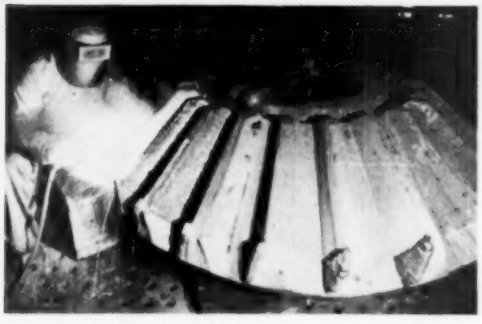

*Fig. 10 Arc deposition of high-carbon alloy on a slabbing mill pinion gear*

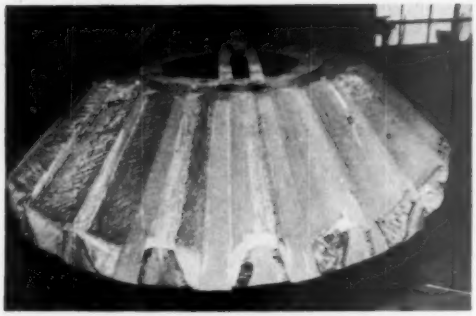

*Fig. 11 Finished slabbing mill pinion gear, restored to a full-length new life by building up and hardfacing*

permits considerable dimensional restoration at the same time that it provides a good wearing surface, further increasing the economy of the job.

In Fig. 12, a gas engine valve is shown being both restored to dimension and hardfaced for longer life. The stem is built up with a 0.50–0.60 carbon electrode which will restore its dimensions and provide suitable wearing characteristics. The seat of the valve, however, is hardfaced with a high-temperature service material of the nonferrous cobalt-base class to provide impact and corrosion resistance at high temperatures, such as this part of the valve encounters in service.

Such uses of two or more materials on one part are often the answer to an otherwise difficult hard-facing problem. One area of a part may very well have to meet different service conditions than another, and in such cases, only the use of different alloys will solve the problem.

## TECHNIQUES AND METHODS

Naturally, the success of any hardfacing job will depend on the way in which the material has been applied. Generally, a competent operator, following the manufacturer's recommendations as to method and procedure, will encounter little trouble. There are, however, a few points to keep in mind:

*Fig. 12 Depositing high-carbon alloy on the stem of a gas-engine valve, with a cobalt-base, heat-resistant alloy on the seat*

1. *Preheating.* Preheat is one of the most valuable adjuncts on many hardfacing jobs. It helps obtain a good bond by loosening surface films, and it tends to eliminate the threats of cracking and distortion which may arise in many jobs.

2. *Cooling.* Slow cooling, particularly with preheated work, is another essential technique. Some materials, however, will not yield their maximum hardness unless cooled fairly quickly, and this must also be considered in the individual case.

3. *Welding Method.* Some alloys are only weldable by the oxyacetylene flame; some are only applied by the arc. Most, however, may be applied as either rods or electrodes, and in such cases careful consideration should be given to the results desired, for they are not quite the same. Factors of cost, properties obtained and working requirements all enter into this question. Generally, oxyacetylene deposits will be smoother, will give less dilution of alloy materials and will cost slightly more to apply. The arc is less costly, faster and penetrates deeper. The flame is usually regarded as more suitable for demanding, critical jobs; the arc, for the more routine work with less exacting service requirements.

Whatever methods are used, careful supervision and control of quality is worth while, whether in the steel mill or elsewhere, to assure uniformity of results and consistent benefits from the possible savings. Steel mill experience, with numerous parts which are processed in batches and on a steady basis, has proved that many hardfacing jobs can be quite readily reduced to a standard procedure, and where this is possible, it is advantageous for all concerned.

## ECONOMIES

The economies obtained in specific instances by hardfacing, steel-mill equipment range all the way from the "highly satisfactory" to downright amazing savings. Those summarized below are only a selected few, but represents the kind of results obtained.

Roller guides, used in sets of six to guide bar stock to the rolls, costing $30 each new and having a life of a few days, are faced with a cobalt-base heat-and-abrasion resistant alloy at a cost of $10 to $12. The hardfacing operation can be repeated many times, so the original cost of the part becomes negligible over its extended life, which is several times that of the original unfaced part, totaling better than 12,000 tons of product. The savings in these parts, as in many others, arise chiefly from the extended useful life, and consequent great reduction in shutdowns.

Side mill guides, costing about $36 new and unfaced, are hardfaced with a high-alloy ferrous material (approximately 42% total alloy, 4.5% C, 30.0% Cr, 6.0% Mn, 2.0% Si) at a cost for material and labor of $66. The resulting guide is good for 60,000 tons of product, as against 20,000 for unfaced guides. Thus $66 spent for hardfacing buys as much guide life as $108 spent for unfaced guides, and further savings result from the elimination of two shut-down-and-replacement operations.

Open-hearth charging peels, although no dollar costs are available, show obvious savings when faced with the low-alloy air-hardening material. Life increases of 400%, and even 500%, are reported by the mills using this procedure. The resulting reduction in maintenance, in production interruptions and in parts inventory is obvious.

Sintering plant pug mill blades illustrates the kind of saving that can be obtained on inexpensive parts. These blades cost only 70¢ each. They are hard faced for 15¢, and the hard facing can be renewed indefinitely at about 8¢ per operation. The life of the original mild steel blade is about one week—hardfacing triples it. A high-carbon, low-alloy material, designed for resistance to sliding abrasion and impact, is used. In this case, by checking and refacing before the previous hard facing has worn completely off, the blades can be kept in use at very low cost and the mill is kept running at peak efficiency.

A shear blade, used in shearing billets from $6^1/_4$ to $7^3/_4$ in. square costs $35 as a new, heat-treated tool steel blade. It is hardfaced with a high-temperature service, cobalt base alloy at a cost of $12. The original blade is good for 3000 tons of product, the hardfaced blade for 75,000 tons—25 times the life. Twelve dollars spent for hardfacing bought as much shear blade life as $875 spent for new blades, and these figures do not reflect savings from reduced downtime and lower maintenance costs on the mill.

A top die, used in the press forging of rounds, costs $200 new. It lasts 16–20 hr. Hardfaced with low-alloy, air-hardening material, at a cost of $17.50, its life is 72 hr. This is the reclamation, for $17.50, of a $200 part, with a new life of three times the original—and the operation replaces the costly machining and heat treating of the die which by previous methods restored it to a life no longer than it had in the first place.

It is difficult—even impossible—to describe the entire field of steel mill hardfacing applications in any one paper. The parts of that field we have been able to cover, however, may give some indication of the real usefulness of this process where it is as intelligently and realistically applied as it is in the steel mills today. Reduced costs, increased efficiency, and steadier production are the principal benefits which can be obtained in varying degrees by other industries working along the same lines the steel mills use.

# 1949 Adams Lecture

# Fatigue of Structural Joints

***Advantages and disadvantages of arc welding as a means of fabricating steel structures, importance of fatigue, design values***

*by Wilbur M. Wilson*

## INTRODUCTION

ONLY a few years ago welding was not recognized as a means of fabricating steel structures. Fifty years ago, as an engineering student strolling through the college forge shop where a 1-in. round steel rod was being welded at a hand forge, the writer was told that an engineer did not consider a weld as having any strength. Today, thousands of tons of steel are being fabricated by arc welding every year. This being true, it is in order for structural engineers to consider whether or not their faith in arc welding as a means of fabricating steel structures is justified.

In discussing this subject, it is not the intention of the writer to either promote or discredit welding. The fact that fabrication of steel structures by arc welding is practiced to a large extent is evidence that it has some advantages. The fact that its use is not universally approved would seem to indicate that, under certain conditions, it is considered as having some disadvantages. It is the purpose of the writer to discuss the pros and cons of the method.

## FACTORS FAVORABLE TO FABRICATION BY ARC WELDING

As the writer sees the situation, the features which are responsible for the fact that fabrication by arc welding has, to a considerable extent, replaced fabrication by riveting are as follows:

1. Greater economy of design.
2. Smaller investment in equipment required.
3. Greater ease of fabrication for structures of certain types.
4. Greater possibilities for architectural treatment.

These features will be discussed briefly in the following sections.

### *Greater Economy of Design*

The possibilities of a greater economy of design are quite apparent for tension members since the rivet holes reduce the effective net section of members fabricated by riveting. There is no corresponding reduction of the effective net section for members fabricated by welding. This reduction in net section due to rivet holes is seldom less than 20% and may be somewhat greater. Moreover, in addition to the reduction in the effective net section due to the rivet holes, members fabricated by riveting usually require end-connection details in excess of those required for the members fabricated by welding. These further increase the weight of riveted members relative to the weight of welded members for the same situation. It is this very evident saving in the quantity of steel required that is largely responsible for the fact that structural engineers designed structures to be fabricated by welding before all problems related to welding had been solved. The evident economy of material caused the fabricator and the customer alike to discount the possible hazards of the new process.

### *Smaller Investment in Equipment Required*

Another feature of arc welding that has hastened its use is the fact that the equipment required is less expensive for arc welding than it is for riveting. Where riveting is replaced by welding, flame cutting often replaces shearings as a means of cutting the steel members to size. Flame-cutting equipment and welding equipment are relatively inexpensive. Thus a small shop might be able to own the equipment required for fabrication by welding even though it could not afford the equipment for fabricating a riveted structure for the same situation.

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### *Greater Ease of Fabrication for Some Structures*

Some structures, particularly pressure vessels for liquids and gases, can be fabricated more easily by welding than by riveting. The joints of riveted tanks containing liquids or gases under pressure must be caulked. This requires a large amount of both material and labor. And there is no assurance that leaks may not develop in service even though the tank was originally tight. In contrast with this, the joints of a container fabricated with butt welds will not have to be caulked and will require less of both labor and material than would be required for a riveted structure for the same service. Moreover, the welded container will be less likely to develop leaks in service than the riveted container.

### *Greater Opportunity for Architectural Treatment*

Riveted structures are not generally noted for their architectural beauty. Generally, the multitude of details obscures the architectural lines. This is particularly true for structures for which the steel has no covering of masonry to hide the details or to emphasize the lines of the structure as a whole. The radial-cone bottom tank is illustrative of one type of structure that can be developed architecturally more successfully as a welded than as a riveted structure.

## FACTORS UNFAVORABLE TO FABRICATION BY ARC WELDING

The features which are responsible for the replacement of riveting by welding, presented in the previous paragraphs, appear to be valid. But that is only one side of the story. There are also reasons why, under certain conditions, fabrication by welding may not be as satisfactory as fabrication by riveting. The writer believes that the welfare of the welding industry will be enhanced if its shortcomings are realized while the industry is still young, in order that they may be either overcome or avoided. If this is done, the industry may be advanced on its merits and not be hampered by structural failures that might occur if the shortcomings of fabrication by welding were not realized.

The adverse features which the writer believes should be considered in judging the merits of arc welding as a means of fabricating steel structures are as follows:

*a.* The possibility that some welds may be of an inferior quality.
*b.* Insufficient knowledge relative to the fatigue strength of welded joints.
*c.* Undesirable mechanical properties of the metal in the weld and in the heat-affected base metal.
*d.* Thermal stresses.

### *The Possibility of Welds of an Inferior Quality*

One feature in connection with the fabrication of steel structures by arc welding that is of great importance is the quality of the weld. There have been instances in which structures fabricated by welding have failed in service, and inspection subsequent to failure revealed the fact that failure was due to an imperfect weld. However, it is generally accepted that a duly qualified welder of high integrity working under favorable conditions, can consistently produce butt welds connecting A.S.T.M., A7 steel plates that will develop the full static strength of the plates. For a member consisting of a butt weld connecting plates to break in the weld when tested statically, it would be necessary for the weld to be definitely faulty, as judged by the present standards of workmanship in the industry.

In the opinion of the writer, butt welds connecting plates are the one type of welded joint that can be made with the greatest assurance. There are other types of welds for which access to some points of fusion during the welding process is not as easy as it is for a butt weld connecting plates. A butt weld connecting two I-beams end to end is an example of the latter. If welds of this type must be made, the difficult features of the weld should be matched by greater ingenuity and superior skill on the part of the operator, and by thoroughness of inspection. But a better plan is for the designer to avoid such welds by planning the structure so that it will not be necessary to use types of welds for which perfect execution is difficult. This is true even if the weld is subjected to only static loads, and it is doubly true if the weld is subjected to shock or to repeated or reversed stresses.

## FATIGUE STRENGTH OF JOINTS

### *Insufficient Knowledge Relative to the Fatigue Strength of Welded Joints*

Although the probability of a static failure of a welded joint can be eliminated by enlightened design, skillful workmanship, the use of good equipment and materials and working under favorable conditions, the possibilities of a fatigue failure should be a matter of real concern to the designers and welders of all structures subjected to moving loads which produce repetitions or reversals of stress.

The possibility of a member failing in fatigue applies to structures fabricated by riveting as well as to structures fabricated by welding. When the results of the writer's first fatigue tests of riveted joints were published,[1] the opinion was expressed by members of the profession that the tests did not represent field conditions or there would have been fatigue failures in the members of the older bridges in service. The fact overlooked in coming to this conclusion was that the time had not yet arrived when fatigue cracks were due to develop in the bridge members. A member that might fail in fatigue at 2,000,000 cycles may not show any evidence whatsoever of an impending fatigue failure at 100,000 cycles, 500,000 cycles or even at 1,000,000

cycles. Fatigue is an old age disease. For an engineer to say that a bridge member will not fail in fatigue after 75 years because no fatigue cracks have been discovered after 20 years of service, is equivalent to a twenty-year-old boy boasting that he will never have rheumatism because he never has had it. With the bridge as with the boy, the time for the crippling effect of age has not yet come.

In a paper presented before the Western Society of Engineers entitled, "Fatigue a Factor in Structural Design,"[2] the writer enumerated the conditions most likely to result in a fatigue failure, and then enumerated the members of a riveted railroad bridge most likely to fail in service. Shortly after this paper was published, the Engineer of Bridges of one of our large railway systems called the writer on the long-distance phone and said, "I have read your paper, Fatigue a Factor in Structural Design. I note what members of a railroad bridge you say are most likely to fail in fatigue. I have had those members inspected for some of our bridges and find that some of them contain fatigue cracks."

Since that time, bridge inspectors have had a special search for fatigue cracks added to their other tasks, and in this inspection they have benefited by our growing knowledge of the conditions under which the formation of fatigue cracks is most likely to occur. As a result, some 400 fatigue cracks have been discovered in the steel members of our riveted railway bridges in service. And, thanks to the more intelligent inspection that has resulted from our increased knowledge, these cracks have been discovered early enough to prevent the loss of life, and, with a few exceptions, early enough so that repairs could be made at a relatively small cost.

Bridge engineers did not realize that some of the riveted bridges which they were building were susceptible to fatigue failure until they had accumulated a supply of bridges that represented the results of some 50 years of construction. They now face the necessity of keeping these bridges in service, even though some of the members are deficient in their ability to resist fatigue. It is because he desires to prevent the engineers of 1980 and 1990 from having to face a similar situation with respect to welded bridges now being built, and which may be deficient in their resistance to fatigue, that the writer has devoted such a large part of this paper to the problem of fatigue in connection with the design and construction of welded bridges.

The factors which have the greatest influence on the fatigue strength of a steel structural member are:

*a.* The number of repetitions of a stress cycle of near maximum stress to which the member will be subjected during its life.

*b.* The ratio of the minimum to the maximum stress in the stress cycle.

*c.* The character of the stress-raiser.

These factors are discussed in the following sections.

### *a. The Number of Repetitions of a Stress Cycle to Which the Member Will Be Subjected*

A member that is intact after 100,000 repetitions of a stress cycle may fail at 2,000,000 repetitions of the same stress cycle. Tests show that for a given member and for the same ratio of minimum to maximum stress in the stress cycle, the fatigue strength corresponding to failure at 2,000,000 cycles is approximately $^2/_3$ as great as the fatigue strength corresponding to failure at 100,000 cycles. That is, speaking approximately, $F_{2,000,000} = {}^2/_3$ of $F_{100,000}$ where, for a given member and a given cycle, $F_{2,000,000}$ is the fatigue strength corresponding to failure at 2,000,000 cycles and $F_{100,000}$ is the fatigue strength corresponding to failure at 100,000 cycles.

The fact that a certain member of a railroad bridge is intact after 10, 20 or 30 years of service is no evidence whatsoever that it will be intact after 50 or 75 years of service. The Interstate Commerce Commission, in evaluating railroad bridges, uses a life expectancy of 75 years. Riveted railroad bridges that are now developing fatigue cracks are 30, 40 or 50 years old. There is not a single welded bridge that has been in service long enough for its record of no fatigue cracks to be of any value whatsoever as evidence that its fatigue properties are adequate. Of course, if fatigue cracks have developed, that fact is incontrovertible evidence that its fatigue properties are wholly inadequate.

### *b. Ratio of the Minimum to the Maximum Stress in the Stress Cycle*

The number of repetitions of a cycle of a specified maximum stress necessary to produce a fatigue crack in a given member depends on the ratio of the minimum to the maximum stress in the cycle. A cycle in which the stress varies from compression to an equal tension is much more destructive than a cycle in which the stress varies from zero to a tension. And the latter is more destructive than a cycle in which the stress varies from a maximum tension to a smaller tension.

### *c. The Character of the Stress Raiser*

Any geometrical irregularity in a member, a hole, notch or change in section, is a stress raiser. A severe stress raiser at any section of a tension member subject to an axial load may cause a highly localized stress on the section at the stress raiser as much as two or three times the average unit stress on the same section. That is, the highly localized maximum unit stress on a tension member of a bridge may be more than twice as great as the total load divided by the net area of the section of the member, the stress usually used in designing for static loading. Under static loading, the plastic deformation of structural steel that occurs when the yield-point stress at the edge of the stress raiser is reached, causes a redistribution of the stress. Under repeated loading, the highly localized stress at the stress raiser will not be redistributed by plastic flow,

but, under many repetitions, may cause an incipient crack to form which is an even more severe stress raiser than the one that started the crack. With additional repetitions of the load, the propagation of the fatigue crack is accelerated and failure will eventually occur. It is known that the unit fatigue strength for a structural member with a severe stress raiser may be very much less than the allowable unit static stress for the material from which the member is fabricated.

The above discussion has been limited to a consideration of the effect of primary stresses upon the static and fatigue strength of the members of a structure. Although the writer has no information relative to the extent to which primary and secondary stresses are additive in their tendency to develop a fatigue failure, he believes they are additive to a considerable degree.

According to the American Railway Engineering Association Specifications for Steel Railway Bridges, paragraph 1608, secondary stresses up to 5600 psi. tension and up to 4200 psi. compression may be ignored. This may be justifiable in designing for static strength but, in the opinion of the writer, it remains to be proved that it is justifiable in determining the fatigue strength, especially in members connected with welded joints.

In the opinion of the writer, one of the important research problems in structural engineering that remains to be solved is the influence of secondary stresses on the fatigue strength of structural members and joints subjected to both primary and secondary stresses. Further, he believes that there is a possibility that this problem is more vital for structures fabricated by welding than it is for structures fabricated by riveting.

### *Present Knowledge Relative to the Fatigue Strength of Structural Members*

Space will not permit the inclusion of a comprehensive statement relative to the fatigue strength of various types of steel structural members. Instead, the fatigue strength of a few typical members will be given. These will be supplemented by references to reports of fatigue tests of both riveted and welded structural members to which the reader is referred.

Generally, the writer, in making fatigue tests of structural members, determined the value of both $F_{100,000}$ and $F_{2,300,000}$ the fatigue strength corresponding to failure at 100,000 cycles and at 2,000,000 cycles, respectively. The fatigue strength was determined for the cycles, 0 to tension, and tension to an equal compression. The values for the riveted members are based on the net section of the connected parts; the values for the welded members are based on the gross section of the connected parts.

**Table 1—Fatigue Strength of Various Types of Structural Members**

| *Line* | *Type of specimen* | *Cycle* | *Number of cycles for failure* | *Fatigue strength of net section, psi.* | *Reference No.* Bull. | Page |
|---|---|---|---|---|---|---|
| 1 | Double-strap riveted butt joint | 0 to tension | 2,000,000 | 25,700 to 29,900* | 302 | 79 |
| 2 | Double-strap riveted butt joint | 0 to tension | 2,000,000 | 23,800 to 26,700† | 302 | 84 |
| 3 | Double-strap riveted butt joint | Tension to equal compression | 2,000,000 | 19,700‡ | 302 | 76 |
| 4 | Plates without welds | Tension to equal compression | 2,000,000 | 17,100 | 327 | 23 |
| 5 | Plates without welds | 0 to tension | 2,000,000 | 31,600 | 327 | 23 |
| 6 | Butt weld connecting plates | 0 to tension | 2,000,000 | 22,500 | 327 | 17 |
| 7 | Butt weld connecting plates | Tension to equal compression | 2,000,000 | 14,400 | 327 | 17 |
| 8 | Fillet welds connecting plates | Tension to equal compression | 2,000,000 | 10,700 | 380 | 31 |
| 9 | Fillet welds connecting plates | Tension to equal compression | 100,000 | 15,200 | 380 | 31 |
| 10 | Fillet welds connecting plates | 0 to tension | 2,000,000 | 19,700 | 380 | 31 |
| 11 | Rolled I-beams in flexure | 0 to tension | 2,000,000 | 31,200 | 377 | 29 |
| 12 | Rolled I-beams in flexure. Full length cover plates attached with continuous fillet welds | 0 to tension | 2,000,000 | 22,800 | 377 | 29 |
| 13 | Rolled I-beams in flexure. Full length cover plates attached with intermittent fillet welds | 0 to tension | 2,000,000 | 16,500 | 377 | 29 |
| 14 | Rolled I-beams in flexure. Partial length cover plates attached with intermittent fillet welds | 0 to tension | 2,000,000 | 8,400 | 377 | 29 |

* 23,200 to 19,800 psi., based on gross area of plate.
† 20,000 to 18,400 psi., based on gross area of plate.
‡ 12,800 psi., based on gross area of plate.

The fatigue strengths for several types of structural members are given in Table 1. As shown in this table, the fatigue strength corresponding to failure at 2,000,000 repetitions of a cycle in which the stress varied from a tension to an equal compression, had the following values for various kinds of members: 10,700 psi. for plates connected with fillet welds, 14,400 psi. for plates connected with butt welds with reinforcement on, 19,700 psi.* of net section for plates connected with double-strap riveted butt joints, and 17,100 psi. for plates without welds.

The fatigue strength corresponding to failure at 2,000,000 repetitions of a cycle in which the stress varied from 0 to a maximum tension has the following values for various kinds of members: 19,700 psi. for plates connected with fillet welds, 22,500 psi. for plates connected with butt welds, 26,500 psi.† of net section for plates connected with double-strap riveted butt joints, and 31,600 psi. for plates without joints.

Table 2 gives references to University of Illinois Engineering Experiment Station Bulletins which contain the results of a large number of fatigue tests of structural members.

An engineer designing structural members subjected to repeated and reversed stresses is handicapped by the fact that a knowledge of the fatigue strength of a proposed member may not be available. It is very difficult to estimate the fatigue strength of one type of member from the fatigue strength of another type of member. Nevertheless, an engineer is often called upon to use a type of member for which the fatigue strength is unknown. As an illustration of this situation, a column bracket of the type shown in Fig. 1 is sometimes used to support crane girders in mill buildings. To the writer, the re-entrant angle where the top horizontal flange of the bracket is welded to the vertical flange of the column looks like a bad stress raiser. For a busy shop, the column brackets which support crane girders are subjected to several millions of repetitions of load in a resonable life of the building. Because the suggested bracket appeared weak in fatigue, the writer had fatigue tests made of specimens incorporating the pertinent details of this crane-girder bracket. These specimens were tested on a cycle in which the stress in the top flange of the bracket where it is welded to the vertical flange of the column, varied from 1000 psi. to 24,000 psi. tension. Failure occurred at *A* where the weld connects the horizontal top flange of the bracket to the vertical flange of the column. Failure occurred at 57,300 cycles for one specimen and at 108,100 cycles for a second specimen.

In the opinion of the writer, the fatigue strength of the detail shown in Fig. 1 is low, and the construction is unsuitable for a situation where there are a large number of repeated or reversed-load cycles of stress during the life of the structure.

An engineer designing structural members subject to repeated or reversed loads should develop a sense which will enable him to recognize situations where fatigue failures are likely to occur. Moreover, he should have a fairly accurate knowledge of the fatigue strength of the particular design he proposes to use. This knowledge can come only from tests.

**Table 2—University of Illinois Engineering Experiment Station Bulletins Containing the Results of Fatigue Tests of Structural Members**

| *Bulletin No.* | *Title* | |
|---|---|---|
| 302 | Fatigue tests of riveted joints | 1938 |
| 310 | Fatigue tests of butt welds in structural steel plates | 1938 |
| 317 | Fatigue tests of connection angles | 1939 |
| 327 | Fatigue tests of welded joints in structural plates | 1941 |
| 344 | Fatigue tests of commercial butt welds in structural steel plates | 1943 |
| 350 | Fatigue strength of fillet-weld and plug-weld connections in steel structural members | 1944 |
| 371 | Rate of propagation of fatigue cracks in 12- by $^{3}/_{4}$-in. steel plates with severe geometrical stress raisers | 1947 |
| 377 | Flexural fatigue strength of steel beams | 1948 |
| 380 | Fatigue strength of fillet-weld, plug-weld and slot-weld joints connecting steel structural members | 1949 |
| 382 | The fatigue strength of various details used for the repair of bridge members | 1949 (in press) |
| 384 | The fatigue strength of various types of butt welds connecting steel plates | 1949 (in press |

* The corresponding value based on the gross section of the plates is 13,600 psi.

† The average of four series. The corresponding value based on the gross section is 20,220 psi.

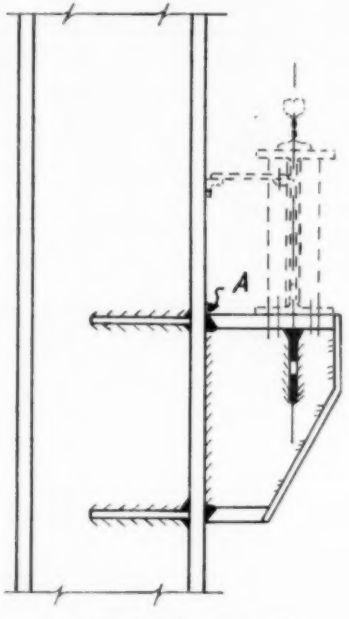


*Fig. 1 Bracket for crane girder*

### *Strength of Plates Connected with Longitudinal Butt Welds*

Two of the features incidental to welding that are sometimes considered to be detrimental are: (1) The undesirable mechanical properties of the metal in the weld and in the heat-affected base metal, and (2) the thermal stresses. It is practically impossible to separate the influences of these two factors. Instead, tests were made which, it was hoped, would give some indication of their combined effect. These tests, made on specimens consisting of plates connected with a longitudinal butt weld, are described in this and the following sections.

Fatigue tests were made on 8 specimens consisting of 5-in. x $^{7}/_{8}$-in. plates, each with a longitudinal butt weld on the center line. The surfaces of all specimens were planed and draw-filed, processes that removed the mill scale and the weld reinforcement. Four specimens were stress relieved by loading in tension to the yield point. The remaining four were tested without being stress relieved. All were tested on a cycle, tension to an equal compression. The values of $F_{2,000,000}$ and $F_{100,000}$ were 15,100 and 20,500 psi., respectively, for the specimens that had not been stress relieved. The corresponding values for the stress-relieved specimens were 16,100 and 22,200 psi., respectively. Each of the above values is the average from two tests. The corresponding values for a plate without weld but with the mill scale on were 17,100 and 27,000 psi., respectively.[3] Apparently the longitudinal butt weld reduced the fatigue strength somewhat, even though the specimen was stress relieved and the reinforcement was machined off. However, the reduction was quite small. If the reinforcement had not been removed, the fatigue strength would have been considerably less than for the specimens with the reinforcement off because of the stress-raising effect of the ripples in the weld.

### *Static Strength of Plates Connected with Longitudinal Butt Welds*

Static tests were made of specimens 5 in. wide and $^{7}/_{8}$ in. thick, consisting of two plates connected with a longitudinal butt weld. The results of the tests are shown in Table 3. Two specimens, Nos. 3 and 6, each had a longitudinal butt weld on the center line. Specimen O was a plate without a weld. All plates were cut from the same parent plate.

Static tests of smilar specimens, 12 in. wide and $^{5}/_{8}$ in. thick having a longitudinal butt weld on the center line, are reported in Table 4.

**Table 3—Static Strength of 5- by $^{7}/_{8}$-In. Plates with a Longitudinal Butt Weld on the Center Line***

| *Specimen No.* | *Yield point, psi.* | *Ultimate strength, psi.* | *Elongation in 8 in., %* | *Reduction of area, %* |
|---|---|---|---|---|
| Average of four coupon specimens | 33,500 | 63,840 | 25.2 | 36.0 |
| 0 | 31,600 | 65,470 | 33.4 | 36.2 |
| 3 | 38,000 | 67,700 | 17.3 | 21.8 |
| 6 | 38,400 | 67,020 | 17.4 | 21.0 |

* *Univ. Ill., Engrg. Exp. Sta., Bull.* **361,** p. 32.

**Table 4—Static Strength of 12- by $^{5}/_{8}$-In. Plates with a Longitudinal Butt Weld on the Center Line***

| *Specimen No.* | *Yield point, psi.* | *Ultimate strength, psi.* | *Elongation in 8 in., %* | *Reduction of Area, %* |
|---|---|---|---|---|
| Average of two coupon specimens | 36,320 | 68,210 | 28.3 | 48.4 |
| 0 | 37,400 | 67,200 | 38.3 | 34.6 |
| 1 | 38,800 | 70,000 | 27.3 | 26.7 |
| 3 | 39,800 | 69,000 | 27.0 | 26.1 |

* *Univ. Ill., Engrg. Exp. Sta., Bull.* **361,** p. 39.

**Table 5—Static Strength of 40- by $^{7}/_{8}$-In. Plates with a Longitudinal Butt Weld on the Center Line***

| *Spec. No.* | *Description of specimen* | *Stress, psi.* | | *Elongation, %* | | |
|---|---|---|---|---|---|---|
| | | *Yield point* | *Ultimate strength* | *On 72-in. gage length* | *Maximum on any 8-in. gage length* | *Reduction of area, %* |
| A1 | Plate without weld | 31,000 | 58,400 | 27.8 | 54.5 | 44.7 |
| A2 | | 31,000 | 61,000 | 27.2† | 48.7‡ | 43.2 |
| Av. | | 31,000 | 59,750 | 27.5 | 51.6 | 44.5 |
| B1 | Unionmelt weld in as-welded condition | 33,000 | 59,500 | 24.5 | 42.1 | 34.4 |
| B2 | | 31,000 | 56,500 | 25.1 | 47.0 | 38.3 |
| Av. | | 32,000 | 58,000 | 24.8 | 44.6 | 36.4 |
| C1 | Manual weld in as-welded condition | 34,000 | 60,900 | 25.0 | 39.0 | 30.7 |
| C2 | | 33,000 | 60,700 | 24.2 | 37.2 | 29.5 |
| Av. | | 33,500 | 60,800 | 24.6 | 38.1 | 30.1 |
| D1 | Unionmelt weld treated | 33,000 | 61,800 | 21.7 | 33.1 | 26.3 |
| D2 | | 33,000 | 59,800 | 25.3 | 44.8 | 39.0 |
| Av. | | 33,000 | 60,800 | 23.5 | 39.0 | 32.7 |
| E1 | Manual weld treated | 33,000 | 62,600 | 23.0 | 35.3 | 29.5 |
| E2 | | 33,000 | 56,500 | 6.9 | 8.2 | 7.2 |
| Av. | | 33,000 | 59,550 | 15.0 | 21.8 | 18.4 |

* *Univ. Ill., Engrg. Exp. Sta., Bull.* **361,** p. 53.

† Measured on a 77-in. gage length and adjusted to the equivalent value for a 72-in. gage length by the use of the diagram of Fig. 33, Bull. 361.

‡ Measured on an 11-in. gage length and adjusted to the equivalent value for an 8-in. gage length by the use of the diagram of Fig. 33, Bull. 361.

Static tests of similar specimens, 40 in. wide and $^3/_4$ in. thick having a longitudinal butt weld on the center line, are reported in Table 5.

The following statements are based upon the results of the three series of static tests reported in these tables.

1. The longitudinal welds had no significant effect on the static strength of the plates, the average unit strength of the specimens with welds being practically the same as for similar plates without welds.

2. The elongation after fracture was nearly as great for the specimens with longitudinal welds as it was for similar plates without welds.

In view of the statements in paragraphs 1 and 2 above, it would seem that a properly made longitudinal butt weld connecting two plates does not appreciably affect their static strength. However, the tests reported in Section 8 indicate that a longitudinal butt weld, even though the reinforcement is machined off, reduces the fatigue strength somewhat. This may be due to the fact that the mechanical properties of the weld metal and of heat-affected base metal are not the same as for the unaffected base metal. Or it may be due to slight imperfections in the weld.

## SUMMARY

In the opinion of the writer, the situation with respect to the use of arc welding as a means of fabricating steel structures may be summarized as follows:

I. Factors Favorable to the Use of Welding as a Means of Fabricating Steel Structures.

1. Greater economy of design.
2. Smaller investment required for equipment.
3. Greater ease of fabrication for some structures.
4. Greater possibilities for architectural treatment.

II. Factors Unfavorable to the Use of Welding as a Means of Fabricating Steel Structures.

There are three possibilities whereby welding as a means of fabricating steel structures might be a source of weakness. They are as follows:

*a.* The possibility of welds of an inferior quality.
*b.* Undesirable properties of the metal in the weld and in the heat-affected base metal.
*c.* Thermal stresses.

All of these are possible sources of weakness. However, it is believed that they can be entirely eliminated or else reduced to the point where they are not serious, and by the following means.

1. Proper design.
2. Proper welding procedure.
3. Skilled workmen working under favorable conditions.
4. Proper supervision and inspection.

The writer has devoted considerable space to a discussion of the possibilities of a fatigue failure in welded structural members. This is justified by the importance of the subject. However, the fact should be realized that relatively few structural members are subjected to conditions which promote fatigue cracks.

The following three conditions are conducive to the fatigue failure of a structural member.

*a.* A large number of repetitions of a stress cycle of near maximum stress.
*b.* A wide range in stress during a stress cycle.
*c.* A severe stress raiser in the member.

If all three of these conditions exist in a member, its life will be short unless the design stress is correspondingly low. If two of the conditions exist in a member, the possibilities of a fatigue failure should be carefully considered. If only one of these conditions exist in a member, the possibility of a fatigue failure is so small as to be negligible.

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# The German Heating Electrode

AN ELECTRODE has been developed in Germany* that is similar to the customary covered electrode for arc welding, but that deposits practically no weld metal. The electrode deposits a slag that is readily removed. The heat evolved by the electrode is used for local preheating and postheating in welding operations. The coating is basic (MgO), and if the arc is sufficiently long no weld metal is deposited.

As an example, the Krupp heating electrode utilizes a core rod 4 mm. ($^5/_{32}$ in.) diameter with a coating, 7 mm. ($^1/_4$ in.) diameter. It is welded, or rather slagged, at 200-amp. straight polarity. The core rod analyzes: 0.13% C, 0.05% Si, 0.46% Mn, 0.027% P, 0.022% S. The coating analyzes 3.2% CaO, 60.4% MgO, 12.6% $SiO_2$, 1.43% FeO, 1.0% MnO, trace $TiO_2$, 0.5% $Al_2O_3$, 5.92% $Fe_2O_3$, 2.5% $CO_2$, 2.8% $H_2O$, 7.7% ($Na_2O$ + $K_2O$), and 0.33% $P_2O_5$. The slag contains 1.42% CaO, 52.05% MgO, 13.0% $SiO_2$, 28.1% FeO, 3.03% MnO, trace $TiO_2$, 0.42% $Al_2O_3$, 0.86% $Fe_2O_3$, and 0.25% $P_2O_5$. The small amount of metal that sometimes may be deposited by the electrode contains 0.02% C, 0.05% Si, 0.05% Mn, 0.020% P and 0.021% S.

* Schottky, H., and Muller, F. H., "Die Wärmelektrode, ein neues Hilfsmittel zur örtlichen Wärmebehandlung und Erwärmung," published in *Schweissen und Schneiden* **31**, (5), 78-81 (May 1949) and note by F. Bischof in the same publication, Aug. 1949, p. 134.

# The Homopolar Generator for Resistance Welding

***This type of generator has been developed so that it is an economical, efficient and reliable stored-energy system for spot-welding applications***

*by Thomas J. Crawford*

SINCE the earlier paper presented at Chicago in 1947 by the writer,* continued development and study of the homopolar generator system has been in progress. Revised designs have been proposed and built with a view to achieving the utmost in economy of construction together with consistent, reliable welding performance second to none in weld quality.

To a considerable degree these aims have been achieved. Equipment is now commercially available using this system. It is capable of welding performance excelled by none of its competitors, and it is priced economically compared to the other stored-energy systems of comparable welding capacity albeit considerably less flexibility.

This year, after two years of actual prototype operating experience, this system was released for commercial use.

The original system as displayed and described at the 1947 Annual Meeting remains basically unchanged. Its basic elements consist of a homopolar generator, a flywheel, a carbon-pile contactor and a three-phase induction motor drive.

Size of the generator has been reduced by increasing the speed and by using welded instead of cast-field frames. It has been made small enough to mount directly in a Size 2 press welder frame as shown in Figs. 1 and 2.

It has been found that increasing collector ring velocities beyond those previously employed requires different composition of brush materials if reasonable brush pressures are to be employed. This change is in the direction of higher metallic contents and fortunately this also gives a brush of higher electrical and thermal conductivity. These discoveries make practical the present collector ring velocities of about 10,000 fpm. and peak current densities of around 1000 amp. per square inch of brush contact area, without excessive brush or ring wear.

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Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

* "D.-C. Resistance Welding Utilizing Kinetic Energy Storage." Presented at the Twenty-Eighth Annual Meeting, A.W.S., Chicago, Oct. 18–22, 1947. Published May 1948 issue THE WELDING JOURNAL, pp. 359–362.

Development of improved brush and collector ring materials is continuing and still further improvement in current capacity at high rubbing velocities may be hoped for in the future. The current density on the present brushes may be increased by increasing the brush pressure. Unhappily, the friction losses and stand-by brush wear increase with higher pressures. In order to minimize this effect, experimental work is now being conducted with air-pressurized brush holders piped to the head pressure valve on the welder so that brush pressure is applied only when head pressure is applied to the welder and the resultant low-duty cycle of brush pressure application effects a corresponding reduction in friction losses and brush wear. Easier generator starting results. This is important because line starting with the heavy flywheel imposes severe duty on the motor. Reducing brush friction at starting offers a definite gain in this regard.

Throughout this development the aim has been to provide brush life of several thousand hours—roughly a year's normal service—and the presently achieved life period is now ordinarily at a value comparable to the life expected from electronic tubes in a.-c. control equipment.

It has been apparent from the first that one of the principal applications for this equipment would be in the field of aluminum alloy spot welding. Early experiment showed that the system was basically consistent enough to qualify for aircraft welding under AN-W-30 Specifications, but, in one respect, tip pick-up, it resembled the condenser-stored-energy welders of the constant polarity type in that one electrode showed pick-up more readily than the other and this pick-up developed rather rapidly for best production practice.

Designing the welder for fast follow-up made a reasonable improvement in pick-up, but another expedient was adapted which gave this system the same freedom from pick-up enjoyed by the low-frequency converter types of welders and by the 60-cycle types using controlled rate of weld current rise (so-called "slope control").

Early work with the carbon-pile contactor on battery welders showed that the rate of current rise was largely dependent upon the rate of rise of air pressure in the contactor cylinder since the carbon disks, at reduced

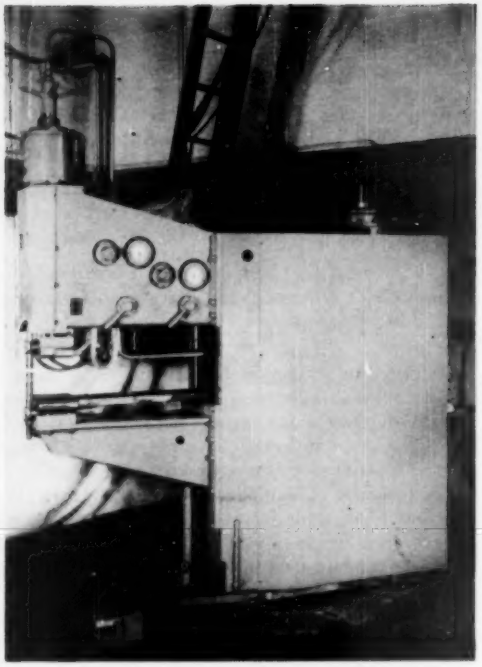

*Fig. 1 Homopolar generator in Size 2 press spot-welder frame (42-in. throat)*

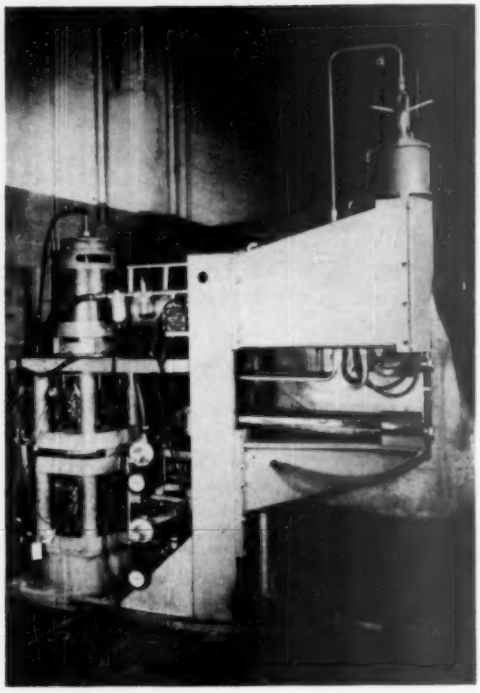

*Fig. 2 Homopolar generator incorporated in welder. Covers removed: 20-hp. motor drive; maximum welding current: 36,000 amp.; maximum force: 4200 lb.*

unit pressure, acted as a series resistor holding down the welding current until the pressure built up. The battery welders had generally enough inductance in the relatively long welding circuit busses to hold down the rate of current rise reasonably well so that, even with rapid contactor closure, the tip pick-up was not excessive.

The shorter leads and lower resulting inductance in the generator system, however, permitted a rate of rise comparable to straight 60-cycle operation and similar tip pick-up resulted when rapid pressure build-up in the contactor was used. To avoid this condition, a simple arrangement of an additional air-regulator and a by-pass throttling valve in the contactor air supply system gives adequate and very flexible control of the rate of current rise and markedly reduces tip pick-up.

The main air regulator normally supplies air to the contactor cylinder at 80 to 85 psi. pressure for the full pressure portion of the contactor closure cycle. The added regulator, in series with the main one, is set for some lower pressure, say 30 psi., sufficient to close the contactor without reducing its resistance to a minimum. A throttling valve by-passing this secondary regulator allows the low air pressure immediately available through this regulator to build up relatively slowly to the maximum pressure determined by the main regulator. As this pressure builds up, the contactor resistance decreases, permitting the welding current to rise concurrently to its peak value.

Figure 3 is an oscillogram of welding current taken while welding 0.081 in. 24 ST Alclad using the original arrangement with immediate full air pressure on the contactor. Here the current rises in less than a cycle (on a 60 cps. basis) to nearly full value. The peaks on the rising wave front are probably due to the impacts on the carbon disks as the pairs of disks connected in parallel close in succession. The momentary high pressure on the carbon disks due to impact momentarily reduces their contact resistance. The gradual rise in current over the latter part of the weld time is probably due to heating of the disks and a reduction of their internal resistance due to their negative temperature coefficient of resistance.

Figure 4 shows an oscillogram of a similar weld cycle using the newer system of delayed pressure build-up in the contactor. Generator terminal voltage is also shown in this oscillogram. The generator used here was of the latest design with sufficient series compound-

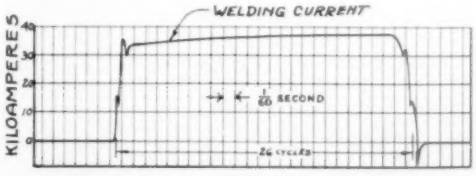


*Fig. 3 Oscillogram with rapid contactor closure*

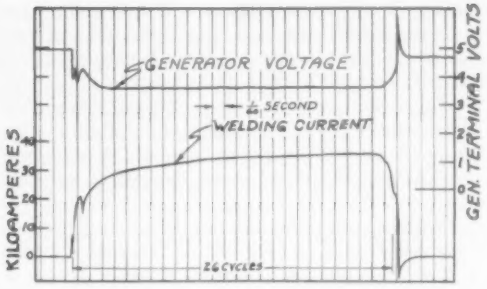


*Fig. 4 Oscillogram with slow contactor closure*

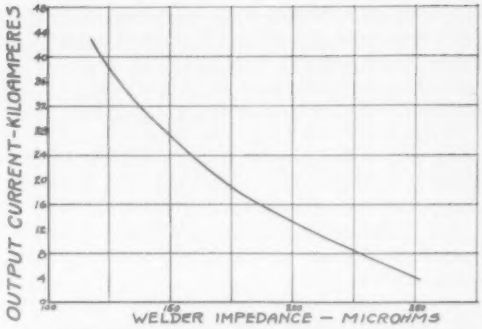


*Fig. 5 Relation of welder impedance to output current*

ing, so that the load voltage held quite constant despite the fact that the speed dropped about 5% during the weld as the flywheel gave up energy at a rate of about 160 kw. With a 20 hp.-driving motor, this weld cycle could be repeated at a rate of ten times per minute continuously without exceeding the rated motor current or dropping below its rated speed of 3200 rpm. (The machine idled at about 3450 rpm.) The open-circuit voltage, after completing the weld, showed a drop in the oscillogram of about 4 or 5%. This weld was started with the generator idling. Two or three welds at a 10-weld-per-minute rate are required to slow it enough to load the particular motor employed to its rated values.

Obviously, if this machine is used for such weld cycles under conditions where the demand, due to working a group of welds rapidly, slows the machine enough to temporarily overload the motor (this is thermally permissible for both motor and generator), the generator voltage in the absence of any compensating influence will decline as much as 15% from its original setting, producing a corresponding drop in weld current.

To overcome this tendency a simple voltage control has been developed. This employs a small electromagnetic regulator of the multifinger-rheostat type to control the output of the exciter. This regulator is blocked during weld interval but operates between welds to correct the excitation so as to hold the generator voltage constant in spite of varying speed. Of course, this control cannot function if the generator is set for full voltage at idle speed, but critical welding requiring precise voltage control is ordinarily not performed beyond 85 or 90% of maximum machine capacity. In this regard, the limitation is similar to that encountered with electronic current or voltage compensation on a.-c. welders.

The more gradual slope of the current rise in oscillogram of Fig. 4 gives a definite improvement in tip pickup conditions and permits consistent welding at lower pressures without expulsion. No very elaborate tests were made to demonstrate this, in view of contemporary work with the analogous "slope-control" for a.-c. welders. However, comparative welds were made on 0.081 in., 24 ST Alclad material, wire-brushed, on a Progressive Size 2 press spot welder of 42-in. throat depth. This machine of a type designed for aluminum welding, has a lightweight aluminum alloy roller mounted head and spring follow-up. A nonsynchronous timer with forge pressure delay was employed.

With a wave form similar to that of Fig. 3, eight or ten welds produced noticeable tip pick-up. Class I tips with 6 in. radius were used. Weld force below 875 lb. produced frequent expulsion.

Using the gradual rise of Fig. 4, more than 50 welds could be made before tip pick-up became evident. The weld force was reduced to 750 lb. without expulsion. Weld time was 26 cycles, forge pressure of 4200 lb. was delayed 16 cycles from start of weld.

With this latter setup a test group of 36 welds was made without cleaning tips. The samples were X-rayed by Detroit Testing Laboratories who reported no visible cracks or porosity. Three of the welds were sectioned and all showed 60 to 65% nugget penetration. Tensile shear tests showed an average of 1644 lb. for the

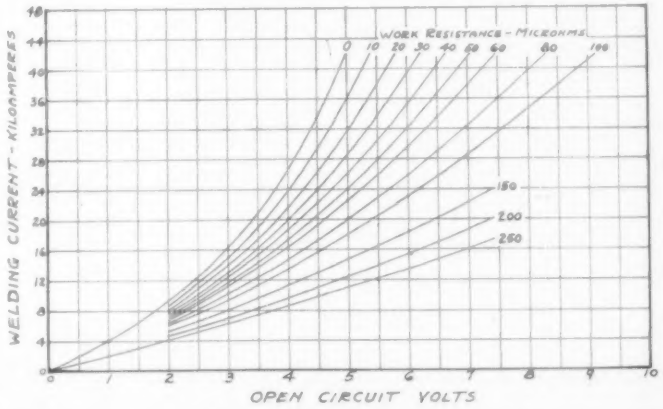


*Fig. 6 Welding current characteristics, Model II Homopolar generator with 42-in. press spot welder (R.W.M.A. Size 2)*

remaining 33 specimens with a minimum of 1505 lb. and a maximum of 1785 lb. Statistically, shear tests for the group showed a standard deviation of 56.6 lb., equivalent to a coefficient of deviation of 3.44%. These values indicate highly satisfactory consistency.

Welds in the test group were made at a rate of 10 welds per minute, starting with the generator at idle speed of 3450 rpm. and ending with it at a speed of 3150–3200 rpm (approximately full-load speed of motor). Automatic voltage regulation was *not* employed which makes the observed consistency all the more notable.

A study of some of the electrical characteristics of the complete welder described above has been made.

A series of short-circuit tests made on the generator-contactor-welder combination brought out the interesting fact that the impedance of this welder system up to the electrodes was not constant as one would ordinarily expect. This impedance actually varies inversely as a function of current; this is due, no doubt, to negative resistance characteristics of the contactor and the brush contacts. Figure 5 shows graphically how this impedance varies with the peak output current.

By calculation from Fig. 5, we can construct the characteristic curves of Fig. 6 for the welder and work, showing the weld current obtainable with various work resistances as open-circuit voltage is varied.

Plotting similar data as arranged in Fig. 7, we obtain the regulation curves for the welder combination operated at various voltages showing how welding current varies with work resistance. The broken line shows a similar curve for a similar machine with a 75-kva., 60-cycle, single-phase transformer having a secondary voltage of 7.58 v. induced.

Some interesting comparisons can be drawn between the two types of machines on the basis of these curves. One of the chief causes of spot-weld inconsistency is known to be variation of work resistance.

As an example, if we consider welding in the stainless steel range, at point *A* with the generator at 5 v. the current is 19,750 amp., the resistance 80 microhms which indicates 31,200 w. energy delivered to the weld. If the work resistance increases, due to surface conditions, low pressure or other reasons, to 110 microhms, the corresponding current will be reduced to 17,200 amp. and the energy will be 32,600 w. or an increase of 4.6% in heat. Comparably with the a.-c. machine operated at 7.48 v. at point *C*, the original current will be 24,000 amp. and the energy level 46,100 w. Again increasing the work resistance to 110 microhms, we find the energy level with 22,950 amp. to be 58,000 w. or an increase of 25.8% in heat. Expulsion would be much more liable to occur in this case with the a.-c. machine.

Similarly in the carbon-steel range, the energy level change from *E* to *F* is 11.1%, while that from *G* to *H* on the curve for the a.-c. machine is 36.8%.

The conclusion can well be drawn that this type of welder with its peculiar electrical characteristics has inherent advantages over the more conventional machines in so far as weld consistency is concerned.

Actual experiment with spot welds on aluminum and with projection welds on steel has repeatedly confirmed this fact.

From the economic point of view, increase in speed and corresponding reduction in size and weight has resulted in a machine whose cost is appreciably below that of capacitor stored-energy equipment and ap-

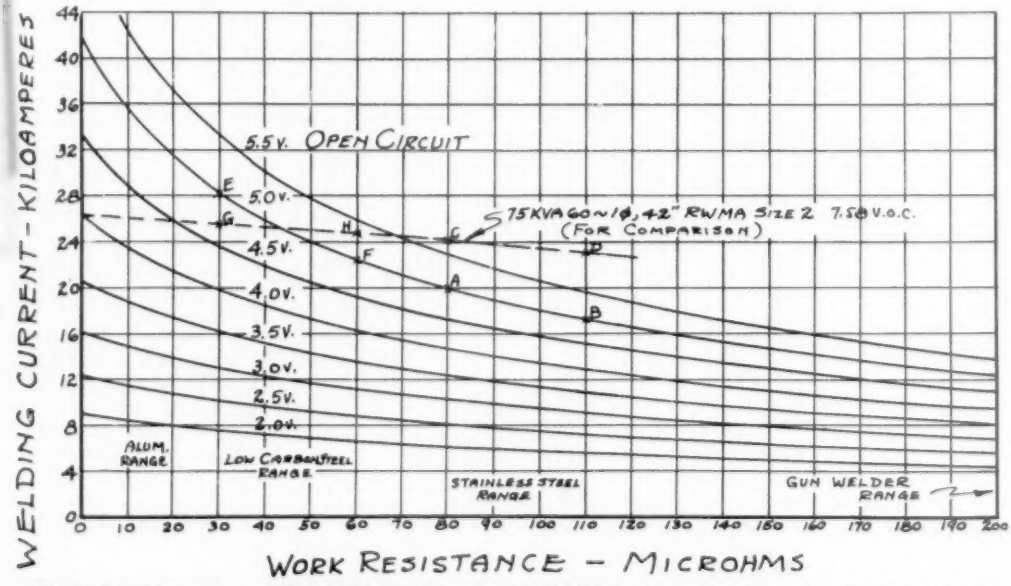


*Fig. 7 Regulation curves of Model II Homopolar generator with 42-in. throat press spot welder (R.W.M.A. Size 2)*

proaching that of three-phase, frequency-changer equipment of comparable capacity. This latter, of course, not using energy storage, requires a much higher welding power line demand.

It has been proved quite practical to use one generator to power several gun welders welding stock of the thicknesses encountered in automotive work. Powering such a generator with a gasoline engine is quite feasible.

Tentative designs have been made for an engine-driven generator to power a portable flash welder for field use providing maximum currents over 150,000 amp. and such designs appear very practical. Comparable equipment for military use is contemplated, as well as for a number of industrial applications.

Continually increasing evidence indicates that this system is one whose usefulness will continue to increase as demands for resistance welding of all kinds in areas of inadequate power supply are encountered.

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# WELDING METALLURGY—Iron and Steel

***The Society has revised the Welding Metallurgy book originally published in 1940. The book has been brought up to date and a wealth of new material added. This book is being reproduced serially in* The Welding Journal. *Copies in attractive imitation leather covers are available at $2.50***

***by O. H. Henry, G. E. Claussen and G. E. Linnert***

## Chapter 7
## EFFECTS OF ALLOYING ELEMENTS

Seldom do we find that a metal about to be welded is a *pure* or elemental metal. This uncommonness of pure metals is simply a result of our learning that the properties of useful metals like aluminum, copper, iron, and so forth can be markedly improved by the addition of other elements. Therefore, the majority of materials which we weld are *alloys* of two or more metals. Even the so-called pure metals, which we occasionally do handle, often contain small amounts of other elements. These elements consist not only of the residual impurities which cannot be eliminated entirely, but also deliberate additions of very small amounts of elements which facilitate the casting and processing of the metal. Nickel, for example, may contain a small addition of manganese to minimize hot shortness induced by residual sulphur. Since these additions do not change the properties and characteristics from those of the pure or elemental metal, we feel that it is not necessary to classify the material as an alloy.

There are many reasons for preparing alloys of metals, the most common, of course, being to improve mechanical properties. More specifically, we may be interested in obtaining higher hardness, tensile strength, notch impact strength, or better ductility. Corrosion resistance also receives considerable attention. Other purposes of alloying would be to improve scaling resistance, alter electrical or magnetic properties, and to improve machinability. This chapter reviews the elements used to form ferrous and non-ferrous alloys. A brief description of the properties of each of these elements is given along with a summary of their effects as an alloying addition. Whatever pertinent information is available regarding their influence on weldability is then given. Later, in Chapter 13 and Chapter 14 of this book, we shall describe in greater detail the relationship between the composition of ferrous alloys and their welding properties.

In reading Chapter 2 covering the types of steels, it may have been deduced that alloys are seldom formulated with an eye to welding properties. In the majority of cases, a familiar cycle of events takes place. First, a designing engineer comes upon the need for a new material with particular properties for an application. He may want good corrosion resistance in hydrochloric acid, or high impact strength at sub-zero temperatures, or perhaps certain minimum tensile strength and ductility values at room temperature. Of course, the test requirements or values which he insists upon are often merely a guess on his part, but circumstances are usually such that his word is final. Next, the metallurgist, through calculation and experimentation, arrives at the combination of elements which forms an alloy possessing the properties demanded by the designer. After all details concerning design and material are thrashed out, the matter of fabrication is brought up. Welding, because of its many advantages, is often chosen by the designer as a means of joining in his plans for fabrication. Keep in mind, however, that the composition of the material was developed to produce particular properties in the finished article. Whether or not the material will lend itself satisfactorily to welding is a matter that the designing engineer willingly leaves to the welding engineer. He is expected to select a welding process and devise a welding technique to produce suitable weld joints in the material. It is the pressure on the last stroke of this cycle that has forced us to adopt the maxim that "all metals can be welded." By following this principle we have reached the present stage where, slowly but surely, welding processes and procedures are devised for joining magnesium, tool steel, heat-resisting alloys, and others.

### SOLUBILITY IN METALS

As an approach to the technical side of the subject of alloying elements and alloys, let us first discuss the events that take place when two metals are combined to form a binary alloy. The customary procedure would be, of course, to bring metals together in the molten state. We find that some combinations of metals are completely soluble in each other and form a homogeneous mixture. This may be true regardless of the proportions or percentages of each involved. As examples, any proportions of molten iron and nickel, tin and lead, or aluminum and copper will commingle to form a homogeneous liquid solution or melt. On the other hand, some combinations of metals may show only partial solubility, and two immiscible layers or melts will appear when the percentage of one metal exceeds its solubility limit in the other. Chromium in quantities up to about 35 percent by weight can be dissolved in copper. However, any chromium added beyond this amount forms a second separate chro-

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mium-rich liquid layer. To complete this story of the solubility of metals in the liquid form, we can point out that in some cases two metals may display no inclination whatsoever to mix or commingle. Iron and lead, also tungsten and copper, are instances of combinations where the liquid metals are practically insoluble in each other.

When we deal with an alloy whose component metals are completely immiscible, the separate layers freeze and remelt at the same temperatures as their respective pure metals. If this immiscibility still exists in the solid state, the properties of the material are just about what would be expected of a mechanical mixture of two metals. On the other hand, if the two metals show some solubility and commingle to form a homogeneous solution or alloy at least in part, many remarkable phenomena take place. First of all, a homogeneous binary alloy usually freezes and melts over a temperature range rather than at a single temperature as we find in a pure metal. Next, one or more phases or forms of crystalline structure may be found in the alloy, and these can bear strong, little, or no resemblance to the crystalline structure of the component metals. The manner in which the crystalline structures undergo transformation is usually entirely new, and all that can be said in a general way about the transformations is that they occur over a range of temperatures rather than at a critical point. Therefore, we have *critical ranges* in alloys, and *critical points* in pure metals.

## EQUILIBRIUM DIAGRAMS

In discussing critical points in Chapter 5 we made use of a hypothetical thermometer to illustrate the level of the critical points for pure iron It was an easy matter to label these points with the temperature and the nature of the structural transformation that occured at each point. To present a schematic picture of the critical ranges and phases of alloys, we would find these hypothetical thermometers awkward to use because we would need a great number of them to cover the many percentage combinations that it is possible to have in a single binary alloy system. Instead, the metallurgist uses a diagram to display information on freezing ranges, transformation ranges, and phases found over the entire series of compositions at any temperature. These diagrams are called *equilibrium diagrams* because the temperatures are determined and the crystalline structures recorded under equilibrium cooling conditions—which means conditions of cooling so extremely slow that changes may take place unconstrained. These diagrams are no more difficult to interpret than our *thermometers*, in fact we can easily show that they are actually plotted from thermometers.

If close attention is given to the eight drawings shown in Fig. 50, there will be no difficulty in becoming familiar with equilibrium diagrams for here we show step-by-step the plotting of a typical diagram. The conventional diagram is two-dimensional, with scales placed horizontally and vertically. On these scales we plot our two variables—composition and temperature. The composition is indicated on the abscissa or horizontal base. The unit markings on the base usually indicate the percentage by weight of one element in the other, although atom percentages are sometimes used. Temperature is indicated on the ordinates or vertical sides. Although the Centigrade temperature scale is appropriate for scientific writing, our practice in this book will be to show both Centigrade and Fahrenheit temperatures—on the right- and left-hand sides, respectively, of the diagrams.

The first step in establishing a binary alloy constitution diagram is to measure the freezing and transformation temperatures of the two pure metals, and then of a suitable number of intermediate alloy compositions. These temperatures are determined by recording a time-temperature graph or *cooling curve* as a small quantity of the molten metal or alloy cools through the solidification and transformation points or ranges to room temperature.

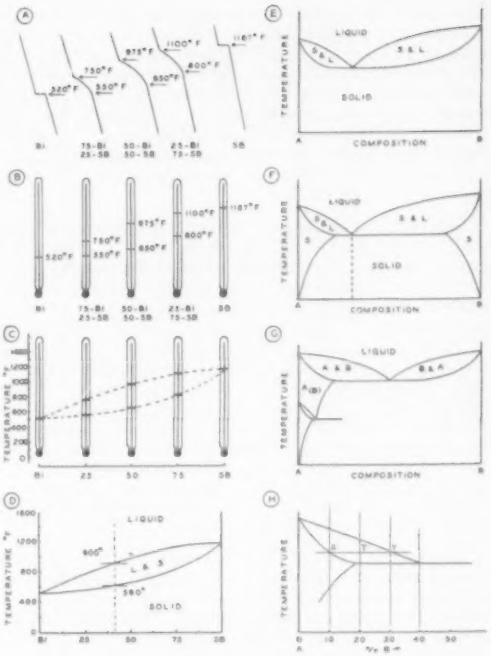


Fig. 50—Development of Equilibrium Constitution Diagrams for Binary Alloy Systems

*Diagram A*—For the purpose of illustration we have selected a simple binary system, that of bismuth and antimony, and have shown how its equilibrium diagram is plotted. In Diagram A we show the cooling curves for pure bismuth, pure antimony, and three Bi-Sb alloys of varying composition. Note the sharp breaks in the curves for the pure metals. These horizontal steps accurately mark the freezing point. During the entire time the metal is undergoing solidification, heat is liberated. The amount of heat given off is sufficient to halt the drop in temperature of the partly frozen sample. When solidification is complete, the liberation of heat stops and cooling is continued. Thus the cooling curve has given us a freezing *point* for the pure metals. Next examine the cooling curves for the three Bi-Sb alloys. The hump in their curves is a result of heat being liberated over a range of temperatures—indicating that freezing is taking place over a range of temperatures. Therefore, the cooling curves give us a freezing *range* for alloys.

*Diagram B*—Here we have drawn a set of schematic thermometers using the temperatures secured from the cooling curves shown in Diagram A. These thermometers provide valuable data, but if we should be asked for the freezing temperature range of an alloy composed of 65% Bi and 35% Sb, we would have to make a rough guess or prepare another thermometer.

*Diagram C*—In this drawing, we have laid down a base line to indicate composition. The line is divided

into units representing percentage by weight. On the extreme left we find 100 percent bismuth; the extreme right is 100 percent antimony. As we move across the line from left to right, we are adding progressively increasing amounts of antimony to bismuth. At the proper points above this composition base line, we have positioned the thermometers from Diagram B. Note the dotted lines drawn through the important temperature levels previously marked on the thermometers, and then pass on to Diagram D.

*Diagram D*—This is a typical equilibrium diagram. Do you recognize it? The dotted lines in Diagram C are now solid. This diagram gives us the freezing range for any Bi-Sb alloy composition. The alloy of 65 percent bismuth and 35 percent antimony, for which we had no thermometer, has a liquidus (start of freezing) of 900° F, and a solidus (end of freezing) of 580° F as determined by drawing a vertical line from the 35 percent Sb point on the base of the diagram and noting where the line intersects the liquidus and solidus. The final bits of information added to the diagram are the phases present in the alloys at the various levels of temperature. The constitution diagram for the Bi-Sb alloy system is simple inasmuch as the two metals are soluble over the entire range of concentration in both the liquid phase and the solid phase.

*Diagram E*—This is a common variation in the appearance of an alloy system freezing range. For the purpose of illustration, we shall call the two metals *A* and *B*. Notice that the alloy consisting roughly of 70 percent *A* and 30 percent *B* has a solidification *point* at a temperature much lower than either of the two component metals. The composition which solidifies at this point is called *eutectic*, and represents the only instance where an alloy may have a freezing and melting *point*.

*Diagram F*—If the metals in the alloy have limited solubility, or if the resultant alloys undergo phase changes in the solid state, the constitution diagram becomes more elaborate. In the alloy system represented by this diagram, the component metals are soluble in the liquid state. The pattern of the liquidus is the eutectic type. However, the metals have only limited solubility in the solid state. An alloy composition to the left of the eutectic point upon freezing will first form crystals of *A* which contain only a limited amount of *B* as indicated by the solid solubility line. We can identify these crystals as phase $A_{(B)}$. As crystals of $A_{(B)}$ continue to form, more of *B* is relegated to the yet unfrozen alloy. This mechanism of freezing continues until the temperature drops to a level just above the solidus line where we find that the remaining liquid has been enriched with *B* until its composition has been shifted to the eutectic point. The remaining liquid then solidifies at the solidus temperature as a eutectic mixture of $A_{(B)}$ crystals and $B_{(A)}$ crystals, often forming peculiar and characteristic structures or patterns. An alloy composition on the right-hand side of the eutectic point, of course, will reverse this performance. The first crystals to form on freezing will be $B_{(A)}$, and consequently the remaining liquid is enriched with *A*. The mechanism, however, is exactly the same.

*Diagram G*—In the vicinity of a transformation, solid solutions of two metals may behave as liquid solutions behave in the vicinity of the freezing temperature. This diagram shows how a transformation takes place in the solid phase $A_{(B)}$, which is predominantly metal *A* with a small amount of metal *B* in solid solution, upon cooling to a lower temperature. The diagram shows that transformation takes place over a *range* of temperature except in one particular composition where it occurs at a *point*. This composition is therefore called the *eutectoid* composition.

*Diagram H*—As a matter of academic interest, we can show how to apply the *Lever law* to an equilibrium constitution diagram and determine for an alloy undergoing a process of solidification or transformation: (1) the percentage of the alloy in the liquid or untransformed state and the percentage of the alloy in the solid or transformed state, and (2) the composition of each of the phases existing at any given temperature level during the process. Our diagram shows an enlarged section of a typical diagram. At a point representing an alloy of 80 percent *A* and 20 percent *B*, we have drawn a vertical line. When the alloy, as a liquid solution cools to a point designated as *T*, we apply the Lever law by drawing a horizontal line through *T*. From the points at which the horizontal line intersects the solidus and liquidus, we drop vertical lines to the composition scale on the abscissa. Now we can state that at the temperature level *T*, the amount of liquid and solid alloy is indicated by the relative parts of the line *XY*. The percentage of liquid is represented by *XT*, while the percentage of solid is *TY*. The composition of the solid can be found by noting where the vertical line from *X* intersects the abscissa, and that of the liquid can be found by the similar line from *Y*.

## STATE OF ALLOYING ADDITIONS

So far, all that has been said about the state or mode of alloys is that the metals which form them may be immiscible or insoluble, completely soluble in each other, or only soluble to a limited extent. This may be true in both the molten and the solid condition. We shall soon see that it is necessary to know more facts about the exact distribution of one metal in another. For ease of discussion, let us talk about alloys having an iron base, that is, we shall imagine that we are adding alloying elements to pure iron.

### Alloys in the Liquid State

When we add lead to molten iron, we find that the lead is not soluble in the iron, but remains undissolved as globules which slowly sink to the bottom of the iron bath because of their greater density. Stirring is the only way we can keep these globules uniformly distributed. Lead in steel has already been mentioned as an example of immiscibility. When nickel is added to iron, we find that the nickel dissolves, and by this we mean that the atoms of nickel are completely and uniformly dispersed throughout the atoms of iron comprising the bulk of the molten bath. This is also true of any element which is soluble in iron—the atoms or molecules show no tendency to cling together, but freely mix with the iron atoms until the bath is a homogenous iron base alloy.

### Alloys in the Solid State

We have even greater interest in the state of alloy additions in the solid condition. As the first case, let us consider alloying elements which were immiscible in the liquid iron, and are likewise insoluble in the solid iron. We usually find the alloy addition in some easily identified form, perhaps just a layer or crust on the surface if the element's density was less than that of iron, or as globules throughout the iron matrix if their densities were reasonably close, or possibly as a layer on the bottom if much heavier than iron. Stirring the iron bath during freezing would tend to produce a dispersion of globules with almost any combination of densities.

As the second case, we will consider alloying elements

which show solid solubility. Here we find that two different types of solid solutions may exist. If the atoms of the alloying element are roughly the same size as the iron atoms, within about 15 per cent to be more specific, then the atoms of the alloying element will occupy positions in the crystal lattice just like the iron atoms. We call this a *substitutional* type of solid solution. On the other hand, if the atoms of the alloying element are quite small, as would be with carbon and gaseous elements like oxygen and nitrogen, the spaces between the iron atoms are often sufficiently large for their entrance. Because the atoms remain lodged in these interstices, this is called an *interstitial* type of solid solution.

In our third case, the alloying elements may exist in still another state—that of a *compound*. If the alloying element is a metal, then the product is called an *intermetallic* compound; if a non-metal the product is called a *non-metallic* compound. Simple experiments in chemistry show that a compound may exhibit no resemblance whatsoever to the element from which it is formed. For this reason it is difficult to predict the behavior of an alloying element when it forms a compound on entering the metal bath. An example of an intermetallic compound in iron is the formation of an extremely hard, brittle phase with the formula FeCr, when about 40 per cent chromium is added to iron. Sulphur as an alloying element in iron does not appear as such, but forms a non-metallic compound FeS, which is practically insoluble in iron and appears as entrapped globules or *inclusions*.

To summarize this review of the various states in which alloy additions may exist, we can tabulate:

| State of Alloying Element | Conditions Which May Exist in Liquid | Conditions Which May Exist in Solid |
|---|---|---|
| Insoluble | Immiscible layers or globules | Heterogeneous mechanical mixture |
| Soluble | Homogeneous liquid solution | Homogeneous solid solution; either substitutional or interstitial type |
| Compound | May be soluble or insoluble | May be soluble or insoluble |

## GENERAL EFFECTS OF ALLOYING ELEMENTS

Now that the various ways in which an added element may exist in an alloy have been covered, we can take a moment to point out what to look for in the way of effects produced by alloying. This should prove worth while before considering specific combinations of alloys because it will allow us to picture the physical properties and characteristics of the alloy as dictated by the state or mode in which the alloying element exists, and is far more valuable than merely memorizing one or two of the specific reasons for adding a particular alloying element.

### Influence During Freezing

Alloys solidify over a range of temperatures (unless it is a eutectic composition) rather than at a single temperature level as we find in the case of pure metals. The range may be narrow or may spread over several hundred degrees of temperature. A wide freezing range provides an excellent opportunity for forming large grains, and favors segregation. Even in an alloy system which displays complete solubility in both the liquid and solid state, the first crystals to solidify from the liquid are rich in higher-melting point elements. As freezing progresses, the crystals that separate and the material that is added to the existing crystals, are richer in the lower-melting point elements. Fig. 51. Unless cooling is unusually slow there will be insufficient time for equalization of composition between the core of a crystal and the last layers to freeze. The resulting difference in composition between the center and outer portions of a crystal is called *coring*. Coring is often evident, for example, in metal deposited by 18 Cr–8 Ni electrodes. Coring is removed by full annealing.

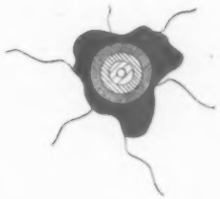

**Fig. 51—Micro-Segregation or Coring. Diagrammatic Sketch in Which the Depth of Shading Increases as the Percentages of Carbon and Alloying Elements Increases**

Frequently observed in cast alloy steel, coring is rarely seen in mild steel weld metal. Instead of the circles shown for simplicity above, coring generally has a dendritic appearance, and is revealed by etching

### Influence on Crystalline Structure

The addition of an alloying element may influence the crystalline form of the solvent metal in several ways. First, if the solvent metal displays allotropic transformation points as a pure metal, then these transformations will occur over a range of temperature when the metals are alloyed. Second, the level of temperature at which the transformations take place may be raised or lowered. Third, the alloying element may markedly affect the nature of the crystalline changes, either suppressing the appearance of certain crystalline forms or by creating the appearance of entirely new forms. In the latter case, it may not simply be a matter of the alloying element forcing its own crystalline form on the solvent metal, but a new, unexpected crystalline structure may appear.

### Influence on Mechanical Properties

Mechanical properties (for simplicity and convenience we can think in terms of hardness and ductility) may be influenced by alloying elements through several different mechanisms.

*Solid Solution Hardening*—A mild increase in hardness can be obtained with very little loss in ductility by adding a quantity of an alloying element which is completely soluble in the solvent metal. The presence of these foreign atoms in either substitutional or interstitial types of solid solutions apparently results in a strained lattice—a condition which naturally results in a slight increase in hardness.

*Precipitation Hardening*—The solubility of an alloying element in a solvent metal may decrease as the temperature is lowered. This condition can be pictured as salt being dissolved in hot water. A considerable quantity of salt may enter solution when the water is hot, but when the water cools some of the salt is rejected from the solution as salt crystals. We say that the salt is present in the water beyond its maximum solubility, and that the crystals have precipitated. The same performance may take place in an alloy of the proper type, for as the solid solution is cooled a portion of the alloying element may crystallize out.

The behavior of an alloy which is capable of precipitation hardening can be made to vary by using certain treatments of heating and cooling. If we should cool the solid solution rapidly (by quenching), the dissolved element may be retained in the solvent metal and thus we will have a supersaturated solid solution. A mild increase in hardness can be expected in the supersaturated solution. However, a much greater increase in hardness

can be obtained by inducing the solute metal (the alloying element) to precipitate out of the solvent metal as fine particles. The crystallization of the particles may be induced in several possible ways: (*a*) by aging the alloy at room temperature, (*b*) by raising the temperature to a level where precipitation starts, or (*c*) by refrigerating the alloy to a low temperature where the condition of supersaturation is more intense and precipitation is forced to take place. If precipitation is made to take place at a lower temperature than it normally would during slow cooling, a finer dispersion of particles is secured and the hardening effect of the precipitate is felt.

*Transformation Hardening*—In some respects, transformation hardening is closely related to precipitation hardening. The scheme of the mechanism is to first select a solvent metal which undergoes a transformation of crystalline form at some convenient temperature level. Next, an alloying element is added which is soluble in the high-temperature crystalline form to an appreciable extent, but is soluble in the low-temperature form to only a limited extent. An alloy containing a suitable concentration of the solute element is heated to a point where its high-temperature crystalline form exists and the alloying element enters the lattice to form a solid solution. Upon cooling the alloy to the point where the crystalline transformation occurs, the alloying element suddenly feels the full effect of limited solubility, or, in other words, it has suddenly become a supersaturated solid solution, and so precipitation takes place. The cooling rate can usually be regulated to produce a fine dispersion of precipitated particles throughout the metal. This structural condition results in a marked increase in hardness, but unfortunately, a marked decrease in ductility also.

## ALLOYING ELEMENTS IN IRON

Because iron is so abundant, is handled in such vast quantities in our steel industry, and is consumed as rapidly by a multitude of users, we usually fail to appreciate the remarkable properties of this element. Let us refresh our memories on what has been said about iron thus far in this book, particularly in Chapter 5 where we discussed the structure of metals.

Iron is a metal of moderate density, having an atomic weight of approximately 56. It has a fairly high melting point, 2795° F to be exact, which in many applications is desirable. The most remarkable characteristic of this element, however, is its ability to undergo reversible changes in crystallographic structure (allotropic transformations) at two specific temperature levels during heating and cooling. At room temperature, the iron atoms crystallize in a body-centered cubic arrangement. When heated beyond 1670° F, the body-centered cubic crystals (alpha iron) transform to a face-centered cubic formation (gamma iron). If heating is continued past 2535° F, the face-centered cubic crystals revert to the body-centered cubic form, which is called delta iron to distinguish it from alpha iron. This crystalline form persists to the melting point. On cooling, the transformations are repeated in the reverse order.

A few words can be said now about the shortcomings of iron, which, of course, will naturally lead us into the reasons why we usually add alloying elements to form steels and ferrous alloys. Iron is progressively oxidized at a fairly rapid rate by rusting and scaling even in mildly corrosive media. We can use alloying elements like chromium and copper to make a substantial improvement in the inherent corrosion resistance of iron. Pure iron has a tensile strength and hardness which are too low for general construction purposes. We have been very successful in improving the mechanical properties of iron by adding carbon for increased *hardness* and alloying elements like chromium, nickel, or molybdenum for increased *hardenability*. Much of our success in altering the mechanical properties of iron can be attributed to the reversible transformation of alpha iron to gamma iron and the wide difference in the solubility of carbon in each of these crystalline forms. As we study the effects of alloying elements it will be seen that additions are made also to alter electrical conductivity or resistivity, magnetic properties, and many other properties and characteristics.

In reviewing the alloying elements used in iron, note that information of a fundamental nature is given first; the atomic weight, melting point, crystalline structure, and so forth. Notice also that most elements can be classified as *ferrite formers* or as *austenite formers*. By way of explanation, certain elements when added to iron will favor the retention of the body-centered cubic crystalline form (alpha iron, or ferrite in steel) and will restrain the appearance of the face-centered cubic crystalline form (gamma iron, or austenite in steel). Upon reaching a critical alloy composition, the face-centered cubic crystalline form may be eliminated entirely and the alloy remains in the body-centered cubic crystalline form at all levels of temperature. An element which influences iron in this manner is therefore called a *ferrite former*. In the same way, adding a sufficient quantity of an *austenite former* can create a ferrous alloy which possesses the face-centered cubic form at all levels of temperature.

### Carbon

A greater variety of changes can be made in the mechanical properties of iron by alloying with carbon, than with any other element. Alloys of iron and carbon up to about 1.7 percent carbon are called *steels;* and above 1.7 percent carbon, *cast irons.*

Carbon is an element with an atomic weight of 12 that can exist in three allotropic forms; amorphous carbon, graphite, and the diamond. It has an undetermined melting point somewhere above 6000° F, nevertheless, solid carbon is readily taken up by molten iron to form a liquid solution. In solid irons, however, the state or mode of carbon as an alloying element is quite complex because carbon can dissolve in gamma iron in appreciable amounts to form an interstitial solution, yet its solubility in alpha iron is very much restricted. The carbon which cannot enter into solid solution with the alpha iron, forms a compound for the most part rather than exist as some form of free carbon. The compound is iron carbide, $Fe_3C$, a material of very high hardness. Because of this trait, we sometimes refer to the equilibrium diagram as the *iron-iron carbide diagram*. However, it is also possible to have the carbon exist as free carbon or graphite, although this form is generally found in higher carbon material like gray cast iron. Experimental work has shown that the true equilibrium diagram for the iron–carbon system should show iron and free carbon (graphite) as the final stable phases.

The iron-iron carbide equilibrium diagram is shown in Fig. 52. Here, the vertical distances, as usual, represent temperature, the Fahrenheit scale being on the left, Centigrade on the right. Horizontal distances represent composition in weight percent carbon. Simply to magnify the space occupied by the lower carbon contents, the composition is plotted logarithmically, there being no hidden significance. The left-hand vertical axis of the diagram represents iron free from carbon, or 0% C. If we picture a specimen of pure iron being slowly cooled, we will recognize these familiar temperatures on the diagram:

*A*—2795° F, freezing point of iron.
*N*—2535° F, transformation of delta iron to gamma iron.
*G*—1670° F, transformation of gamma iron to alpha iron.
*P*—1420° F, approximate point at which alpha iron becomes magnetic.

Now let us examine the diagram as a whole and learn the effects of carbon as an alloying element in iron. The addition of carbon to iron lowers the freezing temperature and causes freezing to take place over a range of temperature. The liquidus (temperature at which solid

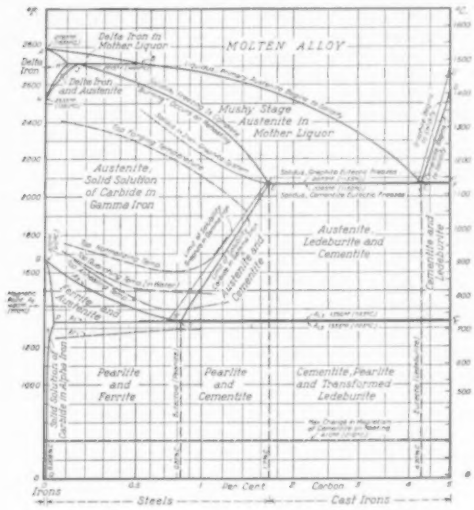


**Fig. 52—Iron-Iron Carbide Equilibrium Diagram (Metal Progress)**
Carbon content is plotted logarithmically for convenience in magnifying the lower carbon range

crystals appear on cooling) is *ABCD*. The crystals which appear in the melt when the temperature reaches *AB* are delta iron. Their compositions are represented by the line *AH*, a part of the solidus *AHJEF*. The term delta iron is used to designate both iron free from carbon and solid solutions of iron and carbon, when it possesses the body-centered cubic crystal form at temperatures just below the freezing point.

The interstitial solid solution of carbon in gamma iron is called *austenite*. The austenite crystals which appear in the melt when the temperature reaches *BC* on cooling are of the compositions shown by the line *JE*. For example, at 2200° F we cannot have a crystal containing 2 percent carbon; if there is melt present the only possible austenite crystal contains 1.5 percent carbon. The austenite freezing along *BC* is called primary austenite to distinguish it from the austenite that forms from the delta iron along *HN* during cooling, which is called secondary austenite.

*HJB*—Peritectic line.
*H*—Delta iron of peritectic composition, 0.08% C.
*J*—Gamma iron of peritectic composition, 0.18% C
*B*—Peritectic liquid, 0.55% C.

The crystals which appear in melts containing over 4.30% C when the temperature reaches *CD* on cooling are iron carbide, or $Fe_3C$. We call this compound *cementite*. The corresponding solidus is not shown, for the reason that its position is not too well known.

*ECF*—Part of the eutectic line.
*E*—Eutectic austenite.
*C*—The eutectic, also, called Ledeburite.

The right-hand end of the eutectic line extends to 6.67% C, corresponding to the composition of cementite, $Fe_3C$. Along *ECF*, the three materials, *E*, *C*, and cementite are in equilibrium. If heat is applied, *E* and cementite react to form a liquid containing 4.30% C at constant temperature, 2065° F. If heat is removed, the eutectic liquid, *C*, discharges austenite *E* and cementite in finely divided, eutectic form. *C* is called the *cementite eutectic* to distinguish it from a liquid *C'* of slightly lower carbon content, which freezes as a eutectic of austenite and graphite. Except in the welding of cast iron, graphite is of no great importance for welding. Liquid is not found below the solidus *AHJEF*.

Aside from the unimportant lines *NH* and *NJ*, there are only five lines in the equilibrium diagram below the solidus, and only two other joints *P* and *S*, which we have not discussed in detail. Lines *GS* and *SE* are analogous to curves *AC* and *CD; molten alloy* (liquid solution) is analogous to *austenite* (solid solution). When solid solution called austenite reaches *GS* ($A_3$) on cooling, crystals of alpha iron appear. Their composition is shown by the line *GP*. Alpha iron in alloys of iron and carbon is called *ferrite*. Ferrite alone, without cementite or austenite can exist only in the area *GPQO*. For example, at 1400° F we cannot have a ferrite crystal containing 0.20% C. We can have ferrite crystals containing up to a maximum of 0.03% C at 1400° F. When austenite reaches *SE* ($A_{cm}$) on cooling, crystals of cementite appear.

*PSK*—Part of the eutectoid line.
*P*—Eutectoid ferrite, containing 0.035% C.
*S*—The eutectoid, containing 0.83% C.

The right end of the eutectoid line extends to 6.67% C, corresponding to the composition of cementite, $Fe_3C$. Along the line *PSK* the materials *P*, *S*, and cementite are in equilibrium. If heat is applied, *P* and cementite react to form austenite of composition *S*, 0.83% C, at 1333° F. On the other hand, if heat is removed *S* decomposes into ferrite (*P*) and cementite. The crystals of ferrite and cementite have the appearance of plates, a thin plate of cementite separating every pair of ferrite plates. This structure consisting of alternate plates of ferrite and cementite is called *pearlite*. The dashed line labeled $A_{r1}$ signifies that the evolution of heat at the eutectoid during cooling at rates commonly prevailing in the laboratory occurs 40° to 80° F below the equilibrium temperature (1333° F) measured during infinitely slow cooling. While grains of pearlite in a pure iron-carbon alloy represent an over-all composition of 0.83% C and the remainder iron, the presence of other alloying elements in the steel may shift the eutectoid point to lower or higher carbon contents. A steel containing 2 percent chromium, for example, would represent a eutectoid composition at about 0.60 percent carbon.

The range over which the transformation of austenite occurs is of especial importance, although this may not be appreciated at this point in our discussion, and is frequently identified by additional letters and digits. The lower temperature of the transformation range (hypoeutectoid line. *PS*) is identified as $A_1$, the magnetic point as $A_2$, and the upper temperatures of the transformation range (*GS*) as $A_3$. The letter *A* stands for the French word arrêt, meaning *arrest*. Since the equilibrium diagram is plotted from data obtained by *cooling* specimens the identification may also include the letter *r* which signifies cooling (*r* from the French refroidissement). In the same manner, a diagram may possibly show the position of these lines on heating and mark them with the

letter *c* (c from the French chauffage). In this case they appear as the $A_{c1}$, and so forth. The lower and upper temperature limits of the transformation range on heating are necessary pieces of information in heat treating steel and are often presented in table form for a list of steels of varying composition.

The usefulness of the equilibrium diagram is open to question because it can be argued that alloys practically never attain equilibrium conditions in practice, particularly in welding where fast rates of cooling are the rule. Nevertheless, the diagram always is essentially correct for the weld melt no matter what the rate of cooling, for the molten metal always crystallizes and will tolerate very little supercooling. It is true, however, that the transformation which normally takes place somewhere between 1670° and 1335° F is suppressed by rapid cooling, a fact which is of paramount importance to us.

Adding increasing amounts of carbon to iron will, in general, result in increasing hardness of the steel. The hardness rises because larger amounts of the hard compound, $Fe_3C$ (cementite), appear in the microstructure. It is just as important to state, however, that the size and distribution of the cementite particles play a large part in determining the hardness. The equilibrium diagram shows that when steel is cooled slowly through the $A_{r3}$-$A_{r1}$ critical range, any cementite which forms at the the $A_{r1}$ is found as thin plates or lamellae between alternate plates of ferrite; a structure which is called *lamellar pearlite*. If the $A_{r3}$-$A_{r1}$ transformation range is suppressed by increasing the cooling rate, obviously, the formation of lamellar pearlite cannot progress in leisurely fashion, but must take place quickly, or not at all. We shall see that when the transformation of austenite is made to take place quickly, and at a lower temperature, either a finer lamellar pearlite is formed, or the cementite appears in an entirely different structural form. From this point onward, we shall make use of the word *hardenability*, which means the inclination of a steel when quickly cooled to undergo the $A_{r3}$-$A_{r1}$ transformation at a lower temperature and in sluggish fashion so that a hard structure is obtained. Chapter 9 of this book goes to great length to show the influence of cooling rate on the mode of cementite in steel, and, in turn, how the hardness is affected.

#### Manganese

Manganese is a grayish-white metallic element which resembles iron in many ways. It has an atomic weight of 54.9, and a melting point of 2268° F. Like iron, it also exists in different allotropic crystalline forms depending upon the level of temperature. From room temperature to 1368° F, the crystalline form of manganese is simple cubic, which is designated as alpha manganese. Heating above this temperature brings about a transformation to beta manganese which has a complex cubic crystalline form.

The properties and characteristics of manganese enable it to act as an important alloying element in iron. Manganese, as compared with iron, has a stronger affinity for oxygen, sulphur, and carbon. When added to molten iron, we find that the manganese will react with oxygen to form manganese oxide, (MnO). This reaction, however, reaches a point of balance or equilibrium and does not go to completion. Therefore, manganese may be considered a deoxidizer, although it is not as powerful in this respect as some other elements like aluminum or silicon. The manganese will also combine preferentially with any sulphur present to form manganese sulphide (MnS), a compound which has only limited solubility in the molten iron and rises to escape in the slag if conditions permit. Manganese sulphide is also practically insoluble in the solid metal and appears as inclusions. Any manganese, beyond the amount required to combine with all the sulphur present, will combine with the carbon in the steel to form manganese carbide, $Mn_3C$, as the steel cools through the $A_{r1}$ critical point. The properties of manganese carbide particles and their appearance in the microstructure are indistinguishable from iron carbide particles.

Besides entering into combination with oxygen, sulphur, or carbon as we have just described, manganese also influences the behavior of steel. Free manganese is completely soluble in molten iron, and enters the lattice of solid iron by forming a substitutional type of solution. The presence of manganese lowers the $A_{r3}$-$A_{r1}$ critical range and makes the transformation of austenite very sluggish—or in effect, increases the hardenability of the steel. Very large additions of manganese, about 12 to 15 percent, suppresses the transformation of austenite so effectively that it does not take place at all even with moderately fast cooling, and the steel remains austenitic at room temperature.

Manganese is usually found as an alloying addition in all grades of steel base metal and filler metal, save perhaps Armco ingot iron. Its purpose is generally threefold; to assist in the deoxidation of the steel, to prevent the formation of iron sulphide inclusions which cause hot cracking difficulties, and to promote greater strength by increasing the hardenability of the steel.

#### Phosphorus

While regarded as an undesirable impurity in most steels, phosphorus is employed as an alloying element in a few cases. This element has an atomic weight of 31 and melts at 111° F. It has an affinity for oxygen, particularly when it is in the form of pure phosphorus in which case it must be protected from the air or moisture to keep it from reacting with the oxygen in these media. When added to steel as an alloying element, it is usually handled as a ferrophosphorus alloy, containing about 20 percent phosphorus.

In molten iron, phosphorus is soluble up to at least 30 percent, a level which is far beyond any iron-phosphorus alloy useful for fabrication purposes. In the solid state, phosphorus forms a compound with the iron, $Fe_3P$, which in turn dissolves in the iron forming a solid solution. At room temperature, alpha iron, or ferrite in steel, can hold about 0.1 percent phosphorus in solution as $Fe_3P$. Phosphorus in excess of this amount exists as $Fe_3P$ particles imbedded in the iron-phosphorus alloy matrix.

Phosphorus is often troublesome in steel because it has a marked tendency to segregate. The phosphorus-rich areas then cause further trouble by rejecting carbon into the surrounding metal. This gives rise to *ghost bands* in the microstructure, which are simply areas containing abnormally small amounts of carbon. In hardened steels, phosphorus tends to make the material somewhat brittle, or in the vernacular of the metallurgist *cold short*.

When present as a residual impurity in any but Bessemer steels, phosphorus usually is found at about 0.04 percent or less. In some special steels, residual phosphorus is held to a maximum of 0.015 percent, but not without steelmaking difficulties. Phosphorus has a mild beneficial effect on the properties of some steels. It is added in amounts up to 0.10 percent to improve the strength and corrosion resistance of low-alloy high-strength steel. Similar quantities help the machinability of many steels.

#### Sulphur and Selenium

Sulphur and selenium are discussed together because these two elements behave in almost identical manner

in iron. In fact, the two elements could be used interchangeably, but for the fact that selenium is much more costly than sulphur. Therefore, we find selenium used as an alloying addition only in the more expensive ferrous materials, like stainless steel.

Sulphur has an atomic weight of 32 and a melting point of 246° F. Selenium has an atomic weight of 79 and melts at 428° F. Both elements show an appreciable solubility in molten iron, but because of their fairly low boiling points, cannot be held in the molten iron in large quantities. In solid iron, both elements exist as compounds, FeS and FeSe, which are practically insoluble. In steel, however, the steelmaker makes it a point to have sufficient manganese present to tie up these elements as MnS or MnSe. These compounds then appear in the steel as globular inclusions (if the metal is cast) or elongated stringers (if the metal is forged or rolled).

For most steels, a maximum of 0.04 percent is adhered to for sulphur or selenium as a residual element or impurity. Steels for special applications, perhaps requiring critical forming properties, or particular weldability requirements, may demand sulphur or selenium contents as low as 0.010 percent maximum. In the opposite direction, alloying additions of 0.10 to 0.30 percent are made of sulphur or selenium because these elements are outstanding in their ability to improve the machining properties of steel. Steels containing sulphur or selenium at this high level are called *sulphurized* or *free-machining* steel. As the cutting tool removes the metal, the sulphide or selenide inclusions cause the chip to conveniently break into short pieces instead of continuing as long, bulky turnings. Also, the inclusions apparently lubricate the tip of the tool and prevent it from galling or seizing with the work piece.

Welding sulphurized steels formerly posed a serious problem because of the occurrence of cracking and gas pockets. These difficulties have now been overcome, and are discussed in Chapter 12 on difficulties and defects.

#### Silicon

The role of silicon as a deoxidizer in steel was described in Chapter 2 on steelmaking. While this earlier discussion will help to stress the need for silicon in certain grades of steel, we should also cover the influence of this element as an alloying addition. Silicon has an atomic weight of 28 and a melting point of 2600° F The crystalline form of the element is cubic. Silicon is not considered a metal, but a *metalloid*. The solubility of silicon in molten iron or steel is unlimited. Solid iron, however, will dissolve only up to about 15 percent, above which level crystals of a compound, $Fe_3Si_2$, appear. The effect of dissolved silicon is to lower the delta-to-gamma transformation range in iron, and raise the gamma-to-alpha transformation range, until at approximately 2.2 percent silicon, the gamma phase is entirely eliminated as an allotropic form and the iron-silicon alloy retains the body-centered cubic crystalline form from room temperature to the melting point. For this reason, we call silicon a ferrite-forming element, because in a sense it has closed a gamma loop in the equilibrium diagram.

While silicon shows some merit as an alloying element for increasing the hardenability of steel, improving mechanical properties, and perhaps aiding the corrosion resistance in some special cases, we find its greatest use as a deoxidizing agent to control the oxygen content and general cleanliness. Silicon and oxygen react vigorously to liberate a large amount of heat and form silicon dioxide, $SiO_2$. This compound is practically insoluble in the molten or solid metal and either rises to escape in the slag, or remains entrapped as inclusions in the metal. Ordinarily, silicon is added in slight excess of that required to deoxidize the steel. In plain-carbon steels we find the silicon from nil to about 0.30 percent depending upon the deoxidation desired. When added for the purpose of complete deoxidation, silicon ranging from 0.10 to 1.0 percent is found.

#### Copper

Because of the poor hot working properties which were experienced in the past with some steels alloyed with copper, this element does not have a particularly good reputation as an alloying element in steel. As our metallurgical knowledge of the alloying effects of copper has increased, we have gradually overcome the problems involved in hot working these materials and now make more frequent use of the element in ferrous alloys Copper has an atomic weight of 64, a melting point of 1981° F, and crystallizes in the face-centered cubic form Copper and iron free from impurities, are completely soluble in the liquid state. When carbon is present above 0.1 percent, complete solubility of copper in iron no longer exists. Its solid solubility in iron is about 10 percent. In the solid state at room temperature the iron will hold about 0.5 percent copper in a substitutional type solution under equilibrium conditions. It appears that plain-carbon or low-alloy steel that undergoes moderately fast cooling can hold at least 3 or 4 percent copper in solid solution at room temperature.

The effects of copper as an alloying element in iron or steel are generally mild. It may be utilized to some extent as a precipitation hardening element in iron or steel by resorting to a solution heat treatment followed by an aging treatment. When present as copper in solution, it increases the hardenability of steel slightly by making the austenite transformation more sluggish A current popular use of copper in steel is to add about 0.25 percent to plain-carbon steel to form a *copper-bearing steel* which is claimed to have a retarded rate of rusting by atmospheric corrosion. Low-alloy steels may contain additions up to 4 percent for added strength and corrosion resistance. Substantial additions of copper are sometimes made to stainless steels to increase their resistance to certain types of corrosive media.

The welding of copper-bearing steels is often looked upon with disfavor. However, as we learn more about the influence of copper in steel, it is realized that our anxiety is predicated on the poor reputation acquired by this element from early hot working difficulties.

#### Chromium

Chromium is a powerful alloying element in iron and steel, and is worthy of considerable study. It is added for two principal reasons: first, it strongly increases the hardenability of steel; second, it markedly improves the corrosion resistance of iron and steel in oxidizing types of media. Chromium is the basic ingredient in stainless steels. The atomic weight of chromium is 52, its melting point is 3430° F, and its crystalline form is body-centered cubic. The solubility of this element in iron and steel is unlimited in both the molten and solid conditions.

Three fundamental facts about the behavior of chromium as an alloying element in iron or steel are: (1) chromium has a high affinity for carbon, and attempts to form complex iron-chromium carbides instead of the simple iron carbide, $Fe_3C$; (2) at high temperatures, it combines readily with oxygen to form chromium oxide, a refractory non-metallic compound; and (3) it is a *ferrite former* in its effect on the crystalline form of iron. Additions of chromium to iron gradually restrict the range over which the gamma or austenitic phases exist, until at about 13 per cent chromium in pure iron the

gamma allotropic form does not appear on heating or cooling. The body-centered cubic form of alpha (or delta) iron is found in the alloy at any temperature up to the melting point. This, it will be recalled, was also the effect of silicon.

We frequently encounter chromium alloy steels in welding, both in the form of base metal and as filler metal. In low-alloy steels where chromium up to 2 or 3 per cent is added for increased hardenability, the chief problem which arises is the avoidance of excessive hardening or possibly cracking in and adjacent to the weld joint. Steels containing 5 or 6 per cent chromium are made because they retain considerable strength at elevated temperature. These steels possess extremely high hardenability and can be welded only with special techniques. Stainless steels contain 10 per cent chromium and higher for corrosion resistance. Chapter 14 is devoted largely to the properties and welding characteristics of stainless steels.

#### Nickel

Nickel is also widely used as an alloying element in iron and steel, and is often added in combination with chromium. Nickel has an atomic weight of 59 and melts at 2651° F. It has a face-centered cubic crystalline structure and is completely soluble in liquid and solid iron. In solid iron, the presence of nickel strongly promotes the appearance of the gamma (face-centered cubic) crystalline form, and an addition of about 25 per cent nickel will cause the alloy to remain in this form at room temperature. Nickel would therefore be considered an austenite former in steel. Nickel dissolved in steel displays no inclination to form carbides or oxides because its affinity for carbon and oxygen is less than that of iron.

The hardenability of steel is increased by alloying with nickel, and for this reason we find nickel present in many low-alloy steels in quantities ranging from 0.5 per cent to as much as 5 per cent. It is a very satisfactory element for increasing hardenability because it often improves toughness and ductility even while increasing the strength and hardness. Nickel is frequently used to secure toughness in steel at low temperature. Additions of nickel substantially greater than 5 per cent are made to secure special properties. In stainless steels, we find nickel ranging from 7 to 35 per cent, resulting in a material of the austenitic type. Nickel in the range of 36 to 40 per cent is employed to form Invar, a special steel with extremely low thermal expansion and contraction. Other than making a steel more hardenable, nickel as an alloy addition causes no difficulty in welding.

#### Molybdenum

Molybdenum has an atomic weight of 96 and melts at 4748° F. The crystalline structure of this element is body-centered cubic. It is a strong ferrite former, and as little at 3 per cent will sustain iron in the body-centered cubic crystalline form. As an alloying element in steel, molybdenum has a very strong tendency to form carbides, and markedly increases hardenability. Small additions of molybdenum, in the order of 0.25 to 0.50 per cent, are usually adequate to secure high hardenability. Molybdenum from 0.5 to 1.5 per cent is often added to low-alloy steels to improve their strength and creep resistance when used in service at elevated temperatures. Stainless steels may contain molybdenum additions from 0.5 to 4 per cent for a number of reasons. The austenitic type of stainless steels may contain this element for greater corrosion resistance to media which is likely to cause pitting, or possibly for greater strength at elevated temperatures.

#### Columbium and Titanium

One particular property which columbium and titanium have in common, that justifies grouping them together for our discussion, is their powerful affinity for carbon. Columbium has an atomic weight of 93 and melts at 4380° F. Its crystalline structure is body-centered cubic. Titanium has an atomic weight of 48 and melts at 3272° F. Its crystalline structure is hexagonal. Both elements have a strong desire to unite with carbon, oxygen, and nitrogen, in steel; titanium having the greater tendency in each case. Both elements also act as ferrite formers on the crystalline structure of iron and steel. When *dissolved* in steel, columbium and titanium are believed to increase hardenability; however, the carbide-forming tendency of these elements is so strong that they are frequently in the structure as *undissolved* carbides and in this way actually decrease hardenability.

Some use is made of titanium as a deoxidizer and as an alloy addition to reduce the hardenability of steel to be welded (by forming carbides which require higher temperatures or longer time to dissolve in the austenite). The greatest use of columbium and titanium, however, is made in stainless steels of the austenitic type where these elements act as *carbide stabilizers*, a role which is described in detail in Chapter 14.

#### Tungsten

The most frequent use of tungsten is made in tool steels, although lately it has been added with good results to a few of the highly alloyed heat-resisting steels. Tungsten is a very heavy element having an atomic weight of 184. Its melting point is 6170° F, so unusually high that it is important to keep it in mind. The crystalline structure of tungsten is body-centered cubic. In steel, tungsten is a ferrite former, has a strong tendency to form carbides—which incidentally are extremely hard—and increase hardenability. The reasons for adding tungsten to tool steel are obviously to increase hardenability and form wear-resistant carbides, but in addition tungsten is effective in sustaining the hardness as the metal rises in temperature to a red heat, a condition not uncommon at the tip of a cutting tool.

#### Vanadium

Vanadium has an atomic weight of 51, a melting point of 3110° F, and a body-centered cubic crystalline structure. Its influence on the crystalline structure of iron and steel is that of a ferrite former. Vanadium has a mild affinity for oxygen, a strong tendency to form carbides, and increases the hardenability of steel. While vanadium has been used on occasions as a mild deoxidizing agent, it is most commonly used as an alloy for increasing hardenability. A minor effect of vanadium which deserves mention is that it reduces austenite grain coarsening during heating.

#### Cobalt

Cobalt has an atomic weight of 59, a melting point of 2723° F, and a hexagonal crystalline structure. Its influence on the crystalline structure of iron and steel is that of a rather weak austenite former. Cobalt has less affinity for oxygen or tendency to form carbides than does iron. It is an unusual element inasmuch as it decreases hardenability in steel. Nevertheless, it is often desirable as an alloying element since it produces a remarkable amount of solid solution hardening when dissolved in ferrite or austenite.

### ALLOYING ELEMENTS IN ALUMINUM

The widespread use of aluminum no doubt can be credited to its light weight and its reasonably good corrosion resistance under ordinary atmospheric conditions or in other mildly corrosive media. Other useful properties are its malleability, high electrical and thermal con-

ductivity, and good light and radiant heat reflectivity. While the cost of this metal is greater than that of steel, aluminum, with a density of only 2.7, will produce more than twice as many articles per pound than will steel. The atomic weight of aluminum is 27, its melting point is 1220° F, and its crystalline structure is face-centered cubic.

Aluminum has a powerful affinity for oxygen and owes its corrosion resistance to a thin protective film of aluminum oxide which spontaneously forms over the surface. Since the oxide of aluminum is white in color, we are not as conscious of the oxidation or corrosion of aluminum as we are of the scaling or rusting of iron. Unfortunately, aluminum is strongly electropositive (anodic) and, when in contact with most metals under galvanic corrosion conditions, will corrode rapidly. It cannot be considered corrosion resistant to common acids, and is strongly attacked by alkalis. Alloy additions have been made to improve the mechanical properties, forming, and machining properties, but alloying has been of little help in improving the corrosion resistance. In fact, most alloy additions lower the corrosion resistance. Some of the alloy combinations which offer very attractive mechanical properties possess such poor corrosion resistance that it is necessary to protect them with a thin surface cladding of pure aluminum; thus, we find the material called *Alclad*. Improved corrosion resistance has also been secured through chemical treatment of the surface.

Aluminum does not undergo an allotropic transformation upon heating, that is, a reversible change in crystalline structure, which might be utilized to obtain transformation hardening. Commercially pure aluminum (Grade 2S) is a soft metal that can be hardened only to a moderate degree by cold working. Some improvement in mechanical properties has been secured by developing an alloy which contains 1.25 percent manganese (Grade 3S). This element produces particles of a hard aluminum-manganese constituent in the matrix of aluminum, and increases the strength and hardness by virtue of a small amount of solid solution hardening plus the effect of the particles hindering movement on slip planes. To secure the greatest strength and hardness obtainable in aluminum alloys, the precipitation hardening mechanism is employed. Copper was originally used as the solute element, being present to the extent of approximately 4 percent. More complex alloys containing small additions of such elements as silicon, magnesium, chromium, and nickel were soon developed and see greater use today.

Aluminum has a higher solubility for many elements above approximately 800° F than at room temperature, and the usual method of carrying out the precipitation hardening operation is to first solution treat by heating the metal above this temperature and then quench. In this condition, of course, the metal is quite soft. Next, hardening is accomplished by a precipitation treatment. This may involve a slight reheating at some convenient time, or merely aging at room temperature, depending upon the particular alloy.

The tensile strength of commercially pure aluminum in the dead soft condition (*O*) is approximately 13,000 psi. This may be increased to 24,000 psi by cold working (*H*). The tensile strength of the precipitation hardening type of alloy may be as high as 80,000 psi.

The chief problem in welding aluminum is brought about by its strong affinity for oxygen. In a fusion welding operation, a heavy crusty oxide film or slag coating forms on the heated metal whenever oxygen is available in the surrounding atmosphere. This oxide film is highly refractory and constitutes a major obstacle in the manipulation of the molten weld pool. Our difficulties with this oxide slag have been relieved through the use of strong fluxes, and, more recently, by the use of the inert-gas shielding atmosphere to prevent excessive oxidation from taking place. The affinity which aluminum holds for oxygen is even a problem in spot welding where it is necessary to remove the thin, invisible oxide film that is ever present on the surface of aluminum sheet by scraping, sanding, or chemical treatment to avoid the erratic electrical insulating effect of the oxide film.

The latest standard temper designations for aluminum and aluminum alloys, and indicating the special properties or condition of the material, are described in detail in the following table:

**Temper Designations for Aluminum Alloys**

| Symbol | Meaning |
|---|---|
| EC | Electrical conductor purity |
| F | As fabricated |
| O | Dead soft annealed condition (recrystallized) |
| H | Hardness obtained through cold working. The letter H designation is followed by one or more digits indicating the nature of the hardening operations and the final degree of strain hardening. |
| | H1—Strain hardened only |
| | H2—Strain hardened and then partial annealed |
| | H3—Strain hardened and then stabilized |
| | Additional digits to indicate final degree; intermediate numbers are permissible: |
| | 2—Quarter hard temper |
| | 4—One-half hard temper |
| | 6—Three-quarter hard temper |
| | 8—Full hard temper |
| | 9—Extra hard temper |
| W | Solution treated condition (870° to 980° F, water quench). Unstable temper |
| T | Treatments to produce stable tempers with or without supplementary strain hardening: |
| | T2—Annealed (cast products only) |
| | T3—Solution heat treated and then cold worked |
| | T4—Solution heat treated |
| | T5—Artificially aged only |
| | T6—Solution heat treated, then artificially aged |
| | T7—Solution heat treated, then stabilized |
| | T8—Solution heat treated, cold worked, and then artificially aged |
| | T9—Solution heat treated, artificially aged, and then cold worked |
| | T10—Artificially aged and then cold worked |

## ALLOYING ELEMENTS IN COPPER

The number of alloys using copper as a basic metal probably exceeds that of any other metal, which is understandable when we consider that copper has been in the hands of mankind for more than 5000 years. This would seem to be ample time to fully explore the possible ways of improving this element by alloying, but strangely enough, we find new copper alloys being developed each year. Copper is another metal which holds an advantage over iron inasmuch as it is resistant to atmospheric corrosion. When exposed to an oxidizing environment, copper slowly forms a protective oxide coating which is green in color and somewhat thicker than the films which we have described as forming on stainless steel or aluminum. This coating on copper is called the *patina*. When heated in an oxidizing atmosphere, copper forms a protective film of black copper oxide.

The atomic weight of copper is 64 and its melting point is 1981° F. The crystalline structure is face-centered cubic at all levels of temperature. The metal exhibits good malleability, and high thermal and electrical conductivity. Copper displays a solubility for oxygen

and will absorb a quantity of this gas if it becomes available during a melting operation. Dissolved oxygen is not desirable where the copper must have maximum ductility. Also, if oxygen-bearing copper is heated above 1300° F in a reducing atmosphere, the reducing gases ($H_2$ or CO) will be absorbed by the copper and will react with the oxygen already present. Sufficient pressure will be developed by the products of this reaction to rupture the copper at the grain boundaries and so render the metal defective.

Obviously, we cannot devote the space required to describe the influence of each of the many alloying elements which are used to make up the hundred or more copper alloys. Therefore, we will only define the general types of copper alloys and the elements which make up their composition.

#### Copper

Copper is usually produced by electrolysis. The cathode bars (99.9 percent purity) may be sold as *electrolytic* copper, or may be refined by various melting operations. During the melting, sulphur and other residual impurities are removed from the metal, and the oxygen content is adjusted to a level where the liberation of oxygen during solidification will compensate for shrinkage during freezing. The latter is a practical method of avoiding pipe or shrinkage cavities. Refined copper (containing about 0.05 percent oxygen) is called *tough-pitch* copper. By adding phosphorus or silicon to the metal, a *deoxidized* copper is obtained. This type has a marked shrinkage upon solidification, but is not subject to the difficulties caused by dissolved oxygen.

#### Brass

Zinc is the element which we add to copper to form *brass*. The chief difficulty in welding brass is the loss of zinc from the metal by evaporation. Zinc melts at 787° F and boils at 1665° F. In describing the oxy-acetylene welding process in Chapter 3, it was mentioned that an oxidizing type of welding flame was employed on brass because the thin film of oxides, which would always be present on the surface of the molten metal, hindered the evaporation of the zinc. Another way to overcome this difficulty in melting and welding brass is by further alloying of the metal to help form a more efficient protective oxide film on the surface of the melt. Elements which can form a film of this kind are aluminum, chromium, vanadium, beryllium, manganese, and silicon. However, aluminum forms a film which is too refractory and cannot be fluxed; manganese oxide does not offer sufficient protection; but silicon performs in excellent fashion and is often added for this purpose.

Besides elements added to prevent loss of zinc during melting, brasses may contain further alloying elements to obtain special properties. As examples, tin will improve strength and ductility, lead will promote free-machining properties, and nickel will increase the strength and improve the corrosion resistance against salt water and other media.

#### Bronze

Originally, the name *bronze* was applied to alloys of copper and tin. Of course, like brasses, tin bronzes were soon alloyed further to obtain special properties. In some alloys zinc was added, making it difficult to class the alloys as a bronze or a brass. Now we find alloys which may or may not contain tin and that are also called bronzes. Aluminum bronzes may contain from 4 to 10 percent aluminum. They exhibit very good corrosion resistance and can be hardened by heat treatment. Other bronzes in use today include those of manganese, nickel, silicon, and silver.

### SUGGESTED READING

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*Ferrous Metallurgy, Volume III*, by E. J. Teichert 1939, The Pennsylvania State College.

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# Arc Welding in Railroad Shops

***The rapid changeover from the riveted to the welded railroad car has led to the mere substitution of welding for riveting instead of a design where welding can be used to give the best and most economical structure***

*by E. Di Liberti*

THE railroads were pioneer users of arc welding and have continually applied new developments and improvements with a view toward decreasing the cost of maintenance and new construction. Because of the numerous regulations, limitations and expense involved, the use of arc welding by railroads has expanded primarily because of the inherent faith in the process by the "welding minded" few in the early days. This pioneering spirit has succeeded in convincing many of the "opponents" and "die-hards" that welding can provide not only economical repair and construction but also superior long-lived new equipment for higher speeds and at lower cost. With this common purpose in mind, the efforts of the welding industry have also been directed toward improving the various welding processes by diligent research.

The past decade has seen the most rapid expansion of welding by the railroads. This was precipitated by the wartime needs and the demands imposed by the large programs for replacement of rolling stock. To meet these demands car builders and locomotive constructors had to resort to the most rapid and economical processes for manufacturing this new equipment. The advent of the all-welded car, while not new to a small segment of the railroad industry, was a revolutionary change because of the tremendous scale with which it has been introduced. These welded cars have demonstrated the advantages of not using old style riveted construction and should be used as a milepost to further improve welded railroad equipment.

Unfortunately, some of the car designs being used at present are simply riveted designs from which the rivets have been eliminated and welds substituted at the discretion of the shop. The reason for this is understandable in that many car programs were literally converted overnight from riveted to welded construction. This was done in the face of ever-increasing orders and a shortage of skilled and experienced personnel. In spite of these difficulties many thousands of well-built cars have been produced. However, the need for design changes on such short notice did not permit adequate studies to be made with the result that many of the advantages available from welding were not fully realized. The importance of good design for welding cannot be overemphasized. Constant efforts must be directed toward utilizing the knowledge gained not only from building welded railroad equipment but also from building ships and other welded structures. Designers must learn to provide the best designs and procedures for welding their products at the lowest possible cost. This requires the utmost cooperation between the engineering department and the shop.

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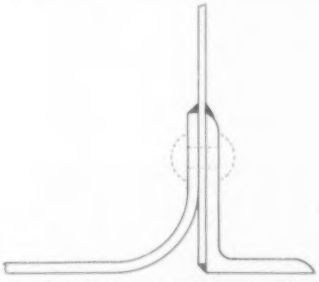

***Fig. 1 Section through lower sill of gondola car; original design used rivets as shown by dotted lines***

An example of a design that is simply a transition from riveted construction is shown in the following illustrations. This particular design is considered faulty not only from a technical point of view but also from a production standpoint in that considerable difficulty was experienced in completing the job. Figure 1 shows a section through the lower sill of a gondola car. This arrangement gave satisfactory results with rivets and was welded as shown by eliminating the rivets. The sides were fabricated and put into position without difficulty. However when the flanged floor plates were inserted the troubles began. Because of inaccuracies in the flanging operation the floor plates had poor fit-up as shown in Fig. 2. The gaps in the floor plates tapered from a tight butt to openings of $^3/_8$ or $^1/_4$ in. Considerable expense was involved in filling up these gaps so as to have a flush floor surface.

***Fig. 2 Plan view of floor plates in gondola car showing fit-up difficulties caused by clamping flanged edges to side sheets***

An improvement can be made as shown in Fig. 3. This arrangement eliminates the flanging operation and the fillet weld at the floor plate is easier to make than on the flanged edge where poor fit-up gave trouble. A saving in welding and weight can be made in that the weld at the bottom edge of the side sheet can be eliminated and the double thickness of metal, side sheet and floor flange can be eliminated. In addition the fit-up of the floor plates can be greatly improved because the plates can be gas cut or sheared to size with greater accuracy. Some corrosion difficulties can be decreased in that the open space or pocket between the flange of the floor sheet and the side sheet is eliminated.

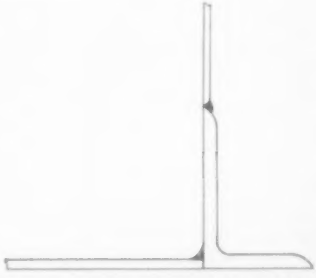

***Fig. 3. Design modified for welding***

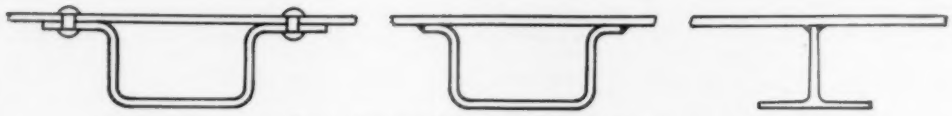

*Fig. 4 Sections through side sheet stiffeners*

*Upper left*, "hat-shaped" member attached with rivets. *Upper right*, "hat-shaped" member welded in place. *Lower center*, improved design using tee section welded to side sheet

A competent designer has offered the following suggestion with regard to decreasing weight and saving cost. The customary stiffener for side sheets is a modification of that used with rivets, as shown in Fig. 4. Some weight saving has been realized by eliminating the rivets and shortening the toe of the flange. By using a rolled Tee section as shown greater stiffness can be achieved, a hot-pressing operation eliminated and the stiffener can be attached with less clamping than the "hat shaped" section.

The next example, Fig. 5, shows how cracking troubles can be avoided by careful design. In welding the center plate to the bolster cracking difficulties were experienced because of cracking through the welds.

By increasing the width of the bolster to permit the weld to be made to the flat surface cracking can be avoided. On a production job of this type the weld must be made with a large diameter electrode in a single pass. In the original design, this meant that the weld could not be made to penetrate to the root. This trouble is eliminated in the modified design.

A related example to further show the effect of sharp corners and the inherent cracking troubles encountered is shown by Fig. 6.

A large number of cars were cracking the center sill from the draft gear pocket as shown. Upon examination it was found that the center sills had been cut very carelessly with a hand torch so that instead of having a nice smooth radius, the ends of the pocket were simply a series of jagged corners. The resultant stress concentration from these jagged edges were responsible for the center sills cracking after only several months of service.

From these few examples it is easy to recognize that in many cases the difference between a poor and satisfactory design is only slight. Yet these slight differences determine whether a job can be properly and economically fabricated or not.

*Fig. 6 Sketch of end of center-sill showing ragged cut and cracks that radiate from draft gear pocket*

Arc welding electrodes are an important link in the welding chain and have been the object of a tremendous amount of research and development. To some the importance and value of an electrode coating is not fully appreciated. This is evidenced by the common question "Why are there so many different types of electrodes and why can't we use one type for all work?" Of course, the predominant source of this question is storekeepers and purchasing departments. However, the same thought is also in the minds of many men directly connected with the welding industry. It is easy to appreciate that the array of electrodes offered today can be confusing to many confronted with the task of selecting an electrode for each job. But it must be remembered that arc welding has grown out of its short pants and the old dilemma as to whether a weld was going to be strong enough to hold the pieces together has been supplanted by very specific requirements for mechanical properties and operating characteristics. The "growing up" process has introduced many complex requirements that can only be met by the large number of specialized electrodes designed for these requirements. As long as there are so many different kinds of jobs to be done there is little hope for the perfect all-purpose electrode that can do all the different jobs satisfactorily.

The railroads have accomplished a great deal with the relatively few types of electrodes normally carried as stock items, the E6010's and E6012's. However, more of the newer specialized types can be found in railroad storerooms now.

Because the problem of selecting electrodes is so important in assuring good welds it is worth reviewing the subject briefly. As mentioned previously the importance of an electrode covering is not always completely understood. There are several basic functions that an electrode covering is expected to control.

In the first place, the covering is expected to control the mechanical and chemical properties of the deposited weld metal. But even though the chemical composition largely determines the mechanical properties, the amount of impurities such as slag and oxides can seriously influence the mechanical properties. For that reason a covering should provide weld metal that is free of injurious impurities.

In addition to providing adequate coverage of the molten weld metal so as to control porosity, the nature of the weld metal protection should be such that cracking difficulties in the heat-affected zone are eliminated. This is a recent innovation in the electrode field and comes from the introduction of the low hydrogen type coverings.

The last and most important factor from an application point of view is the function of an electrode covering to control the usability characteristics. These characteristics are the ones the welder is particularly concerned about but are difficult to define. Such things as the ability of the weld metal to wet the surface of the plate, fluidity, rapidity with which the weld metal freezes and the force and stability of the arc are involved.

While all these factors are involved, it would be extremely confusing to select electrodes on the basis of these factors. For that reason the AMERICAN WELDING SOCIETY has concentrated so much attention on electrode specifications which have succeeded in eliminating much of the confusion that would exist without these specifications and classifications.

In spite of the simplification that has resulted, there is occasional confusion presented by the wide variety of electrodes, particularly when two or more types seem to do the same job. This can be clarified

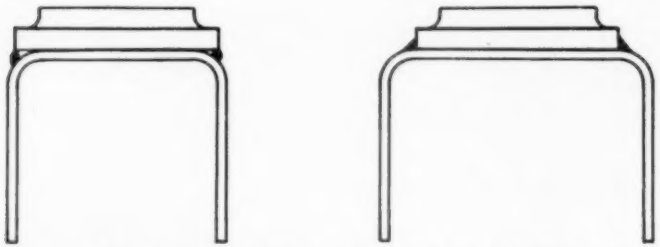

*Fig. 5 Left, section through bolster and center plate showing gaps which caused cracked welds. Right, wider bolster provides better fit-up for single pass welds*

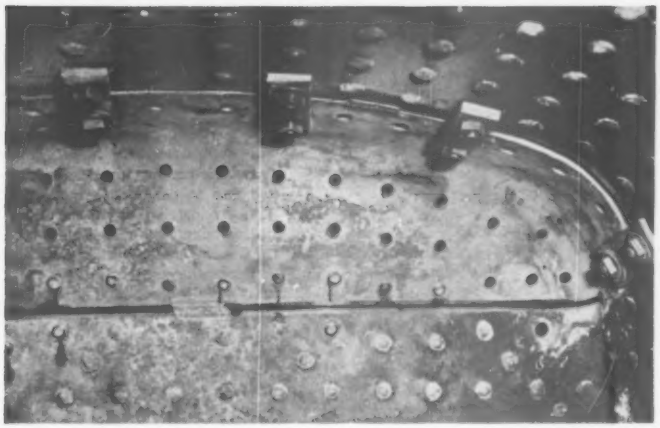

*Fig. 7 New patch on firebox door sheet bolted in position and tack welded*

by a proper understanding as to why several types of electrodes seem to perform well on the same application. The following example is typical.

A large railroad uses different electrodes to patch fireboxes in each of its major shops. The repairs are made in the usual manner in that the portion of sheet to be replaced is cut out with an oxyacetylene torch. The cuts are made between the rows of staybolts, and the fireside edges of the fitted patch and existing sheet are beveled to form an included angle of 60°. Figure 7 shows a new patch on the firebox door sheet bolted in position and tacked and Fig. 8 shows the welded patch. Efforts are made to maintain a $^1/_{16}$-in. root opening. One shop uses E6010 electrodes for welding these patches whereas another shop on the same railroad uses E6012. Each shop is doing a satisfactory job and the reasons for preferring the specific type of electrode are readily understandable. The shop using the E6010 type electrodes has skilled boilermakers that can fit patches within close limits so that welding with the E6010 electrodes can be done readily.

The second shop, while of large size, is in a remote area and apparently suffers from a shortage of personnel with the degree of skill available in the main shop. This lack of skill manifests itself in the form of poorly fitted patches with root openings that vary considerably. Furthermore the skill of the welders is such that difficulty is experienced with the harsher arc and more fluid weld metal of the E6010 electrodes but they succeed in obtaining a workmanlike job with E6012's that have easy handling properties especially on poor fit-up work. This case shows that by selecting the electrode on the basis of operating characteristics alone many difficulties which stem from factors unrelated to electrode selection can be overcome and each type of electrode seems to perform satisfactorily. The shop with the less-skilled personnel learned to overcome their difficulties by selecting electrodes on a trial-and-error basis but the general situation would probably not exist if the railroad had unified welding supervision. Unfortunately the railroad management has not recognized the importance of good welding supervision and as a result welding has been relegated to the rank of a part-time job for supervision by other trades. Centralized supervision would assure more uniform practices in the widely dispersed shops of a railroad and has the advantage of resulting in better work because the responsibility for welding is in the hands of welding personnel. This would also assure that operators would be properly trained and qualified to perform the type of work required regardless of the type of electrode specified.

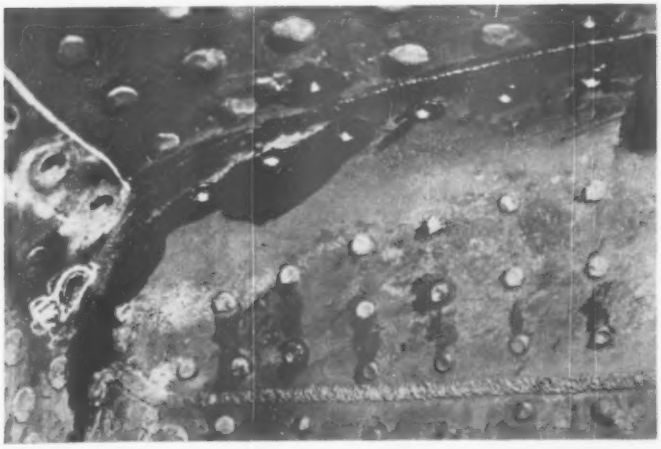

*Fig. 8 Patched firebox sheet, showing finished weld*

The type of electrode to be used on fireboxes has been the subject of much discussion but as shown by this railroad both the E6010 and E6012 can provide satisfactory results. A discussion of the characteristics of these two types of electrodes may be of value.

As is known, the E6010 type provides high-quality weld metal deposits which in general are superior to the E6012 type. However, the greater difficulty of application because of the harsher arc and more fluid weld metal, together with the lower current handling capacity as compared with E6012 tend to make the E6012 the more desirable from a production point of view. While the E6012 electrodes are reputed as having poorer quality of weld metal, recent advancements in this type of electrode show that clean deposits with mechanical properties that exceed those of the E6010 will certainly make the E6012 a still more favored type. These developments, together with efforts to provide electrodes of the EXX12 type that match the low-alloy high-strength steels will permit better and lighter designs of cars.

The introduction of low-hydrogen type electrodes has created rather widespread applications of this type of electrode in railroad shops. Without venturing into the reasons why superior weld metal deposits are obtained where the hydrogen content of the arc atmosphere is reduced, we know that if a job has been properly welded with low-hydrogen electrodes the resultant weldment is the best that can be obtained at the present time. This is in addition to the many other advantages such as the ability to weld steels of higher hardenability than ordinary mild steels and steels of the free-machining high-sulphur type.

One of the earliest applications of low-hydrogen electrodes was to replace stainless types for welding high-carbon wear plates to car trucks. As is customary with any new item, venturesome welders

tried the low-hydrogen electrodes on many other applications. One of the most successful of these trial-and-error applications is in the welding of broken locomotive frames with low-hydrogen electrodes. While some may question the need for low-hydrogen electrodes for locomotive frames, the higher strength, ductility and shock resistance have been proved on at least one railroad by giving better service results.

The introduction of the Diesel locomotive has been responsible for many changes in railroad shops. The repair and maintenance of diesels is radically different from the practices used with steam power. However, the welding problems while possibly more complex and difficult are being mastered rapidly. The repair of frames, trucks, draft gear and cabs are straightforward operations that follow standard practice. Many fabricated Diesel engine frames are repaired by careful control of procedures to thoroughly distribute stresses induced by the repair. For example the replacement of stiffener partitions and insertion of a patch on an engine which "threw a connecting rod" was performed in a very straightforward manner.

Needless to say, many components of Diesel engines are being carefully studied in order to reduce the maintenance costs. For example, the rebuilding of worn ring grooves on aluminum pistons is accomplished by many railroads with considerable savings. This operation is currently performed by the "Heliweld" (tungsten-arc inert-gas-shielded) process. However, the Aircomatic process applied automatically appears to offer even greater speed and economy in rebuilding these pistons.

These new inert-gas-shielded arc-welding processes are becoming absolute necessities for the construction and repair of many stainless, aluminum and nonferrous components as used in late model passenger and dining cars.


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# Ideas for Designing Bases

***Here are some thought starters on welded design furnished through the courtesy of The Lincoln Electric Co., Cleveland, Ohio***

THE following ideas suggest simple details that can be adapted for building rugged, durable machinery bases at low cost. These ideas may be readily modified to suit all requirements of loading, appearance and available equipment in the shop for low-cost fabrication.

A simple base having side members of sheared plate and foundation members of plain rectangular steel is shown in Fig. 1. The rounded corners on the foundation member are made by flame cutting the ends of the rectangular steel strips.

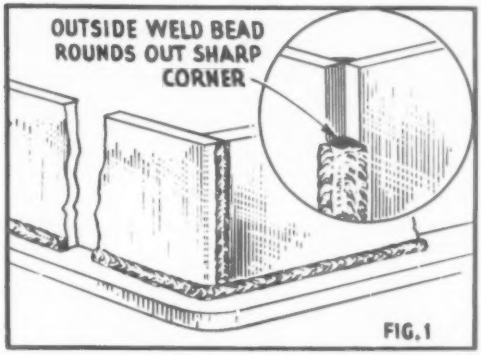


FIG. 1

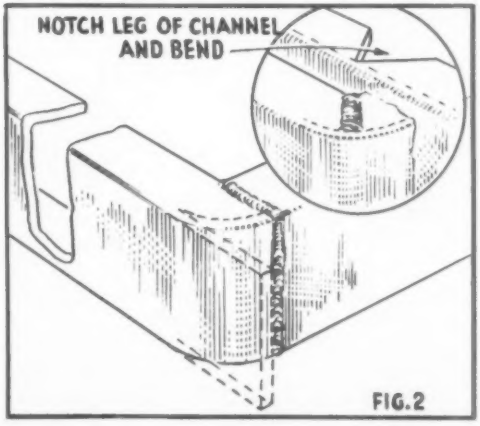


FIG. 2

The corners can be simply butted or positioned as shown.

Figure 2 illustrates the use of simple channel in fabricating the foundation member. Rounded corners

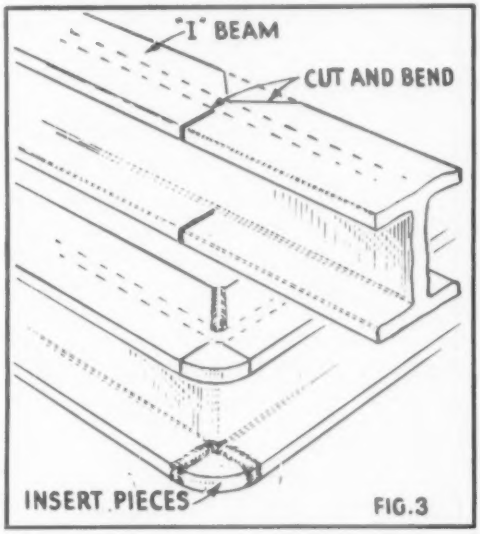


FIG. 3

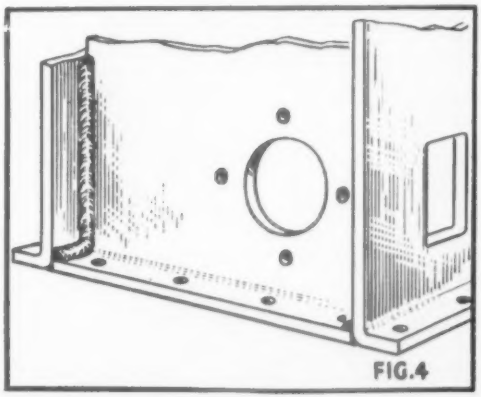


FIG. 4

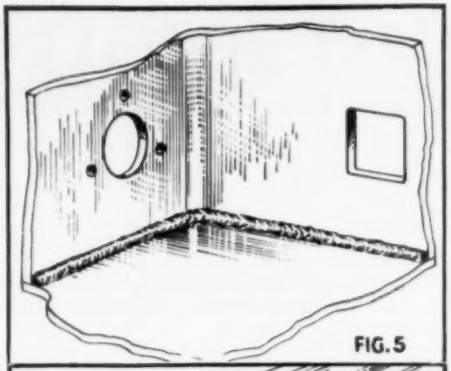


FIG. 5

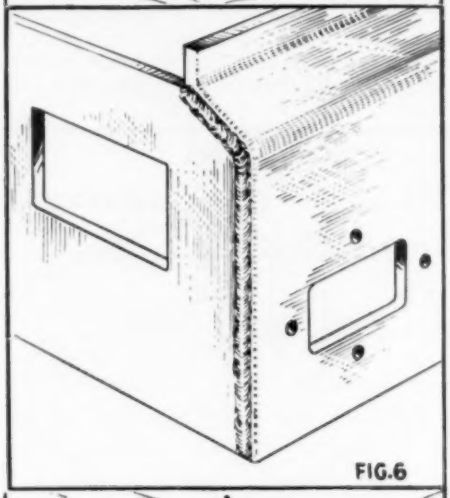


FIG. 6

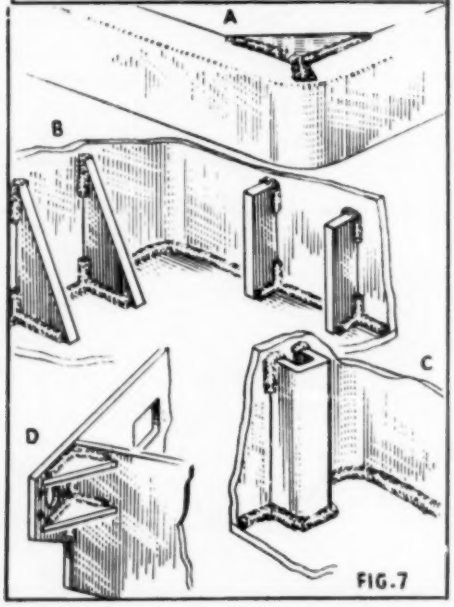



FIG. 7

are achieved by cutting the channel in either one of the ways shown and welding.

The foundation member can also be produced from I-beams as in Fig. 3. Here again, clean, modern appearance is easily produced by flame cutting the I-beam, bending to form and welding in steel inserts.

Both the foundation and side members can be incorporated in a single unit by utilizing bent plate construction as in Fig. 4. With this design a minimum amount of welding is required.

Where the foundation member can be a solid flat plate and side members fabricated from bent plate, the construction shown in Fig. 5 can be incorporated. This design is often followed where totally enclosed or boxed-in construction is required as in oil or coolant reservoirs.

Another construction often adopted in fabricated machinery bases is the use of flame-cut end members and bent side members (Fig. 6).

Various types of stiffeners are utilized in the design of machinery bases. Properly applied, stiffeners provide reinforcement for localized stresses that otherwise might require heavier and more costly machine base members. Figure 7 (*A*) shows the use of a corner stiffener. This is a triangular-shaped piece welded to the channel foundation member to provide extra strength at the corners. (*B*) illustrates a triangular stiffener used to support side members of the base where unusually heavy loads are concentrated. (*C*) is an example of plain rectangular steel strips used to reinforce the side walls. (*D*) shows a corner stiffener of triangular plate to give added support to overhanging frame members.

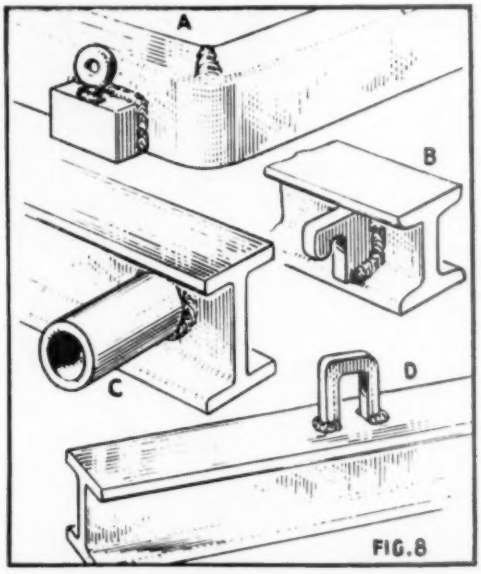



FIG. 8

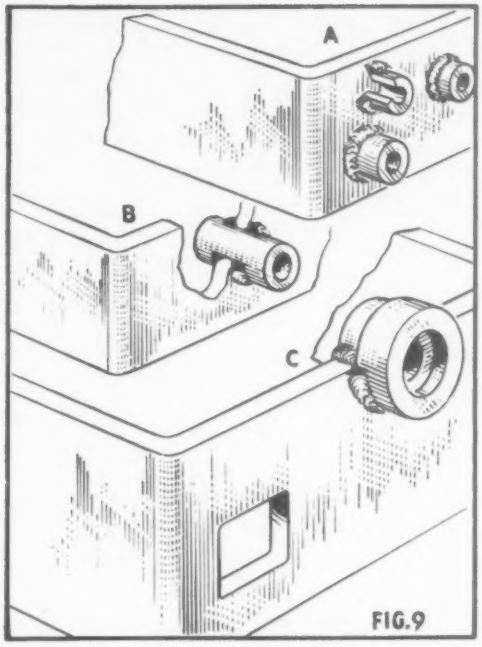


FIG.9

Different types of lifting devices are fabricated and welded to machinery bases. An eye bolt, Fig. 8 (*A*), is welded to a rectangular steel block that is in turn welded to the foundation member. A flame-cut hook (*B*) is fillet welded to the web of an I-beam or to the sides of a channel or directly to the side member itself. Where a rope sling is to be used in moving the machine, heavy wall pipe can be fillet welded to the foundation member as in (*C*). (*D*) shows the detail of a lifting bolt. The member is made from round or square steel bar bent in a "U" and welded.

With arc welding, hubs or bosses used for operating and control mechanisms can be easily positioned in any desired location. Steel disks or washer-like members can be fillet welded to the side walls as in Fig. 9 (*A*). Where added bearing is necessary, a steel bushing can be used as in (*B*). Steel housings for plain or antifriction bearings can first be rough machined and then fillet welded to the side members as in (*C*). Hold-down or leveling pads can be made in several ways, some of which are shown in Fig. 10. As in (*A*) a solid block can be welded to the foundation member or a formed L-shaped piece used as in (*B*). Where the base is to be supported on individual pads, the block (*A*) or L-shaped piece (*B*) can be positioned below the bottom of the foundation member or rectangular pads welded to the bottom of the foundation member as in (*C*). In cases where space restrictions are encountered, a recess can be used as in (*D*) providing outside access to hold bolts or leveling screws.

Pads for attaching auxiliary equipment can be readily adapted as in Fig. 11. (*A*) shows plain pads that can be predrilled and tapped for mounting motors or pumps.

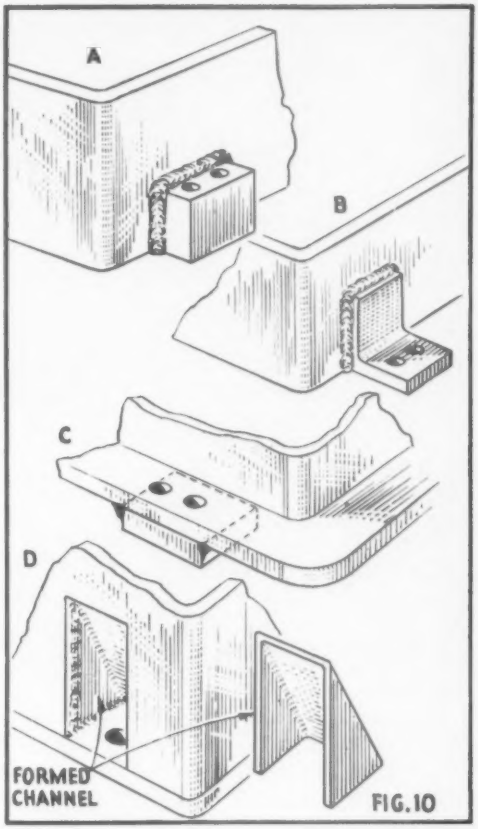


FIG.10

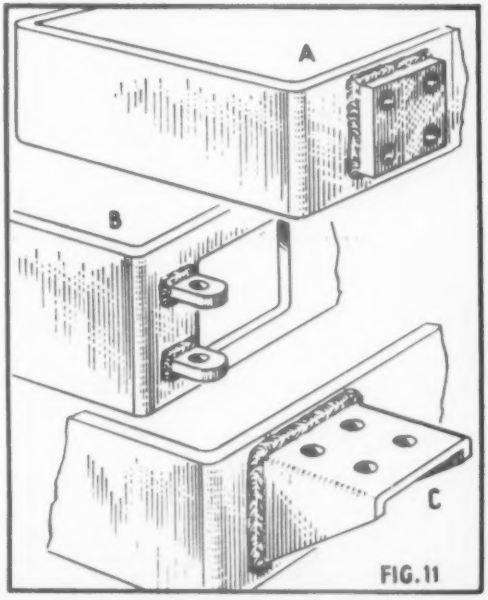


FIG.11

In (*B*) are typical hinge members for holding doors and covers. (*C*) shows a simple mounting bracket of formed steel fillet welded to the side member of the base.

# Clothes Drier

***by J. A. Warren***

THIS collapsible clothes drier is the answer to a busy wash day. It is easy to make, and easy to set up and take down.

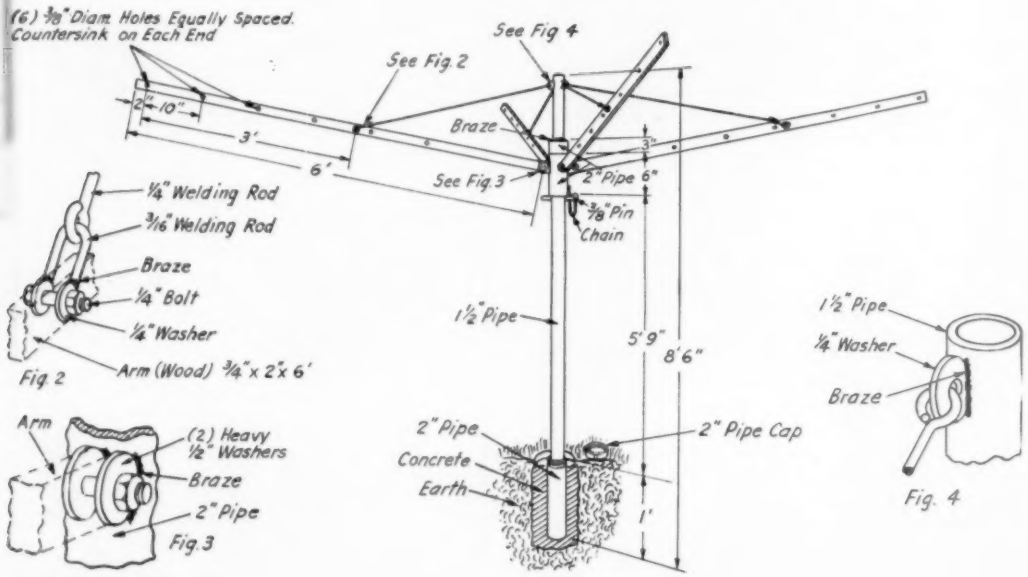
The center post is made from $1^1/_2$-in. pipe. It rests in a socket made from 2-in. pipe sunk upright in a small concrete base. A collar made from 2-in. pipe slides along the center post. Eight $^1/_2$-in. washers, through which the arms are bolted, are brazed to the collar. Another collar made from 2-in. pipe is brazed to the center post. It keeps the sliding collar in place.

The arms are supported by braces made from welding rod. The braces are 3 ft. long and are held by washers brazed to the center post.

A $^3/_8$-in. pin supports the extended arms. It extends through holes in the center post. After the wash is dry, this pin is removed. The collar slips down, and the arms fold up. The drier can then be put away until next wash day.

The 2-in. pipe in the ground is threaded for a cap. The cap screws on the pipe and keeps out dirt and water.

J. A. Warren is with The Linde Air Products Co., Minneapolis, Minn.



# How to Bronze Weld*

*by C. H. Wanamaker*

WELDING with bronze rod—it's called bronze welding or braze welding—is the easiest way to join steel, cast iron, malleable iron and many other metals. It is easy to do because you use a low heat and usually you do not need to preheat the part.

The important things to remember when you bronze weld are to clean the part thoroughly and to heat the metal only as a dull red. This means that you must remove all oil, grease, scale or rust oxides from the beveled edges or the facing edges of the part. The top and bottom surfaces should also be cleaned for about $^1/_2$ in. back from the edges. You can do this cleaning with a grinder, wire brush, file, emery cloth or steel wool.

The surface of the edges to be welded must also be cleaned chemically with a good flux. This means that you need flux on the rod for tinning and you must dip the rod into the flux can often during welding.

## PREPARING THE EDGES

When the metal is more than $^1/_8$ in. thick, the edge of each part must be beveled to a 30 to 45° angle. This beveling helps you to get complete penetration to the underside of the weld. For thinner material all you have to do is clean the edges.

Grinding, chipping and machining are suitable methods for beveling the edges. However, if the part is cast iron, these methods may smear the graphite present in the casting and make it difficult to get proper tinning. The graphite can be removed by quickly heating the edges to a dull red with your blowpipe, then cleaning them with a wire brush when they are cool.

The broken spoke of the steel wheel in Fig. 1 is an example of one of the easiest repair jobs. First, clean the spoke ends and the rim thoroughly. Scratch the metal clean and remove all oil, grease, rust and scale from the ends of the spoke and from the inside of the rim near the spoke. A stiff wire brush or steel wool will do a good job. Now choose a small size welding tip and adjust the blowpipe flame so that it has a slight excess of oxygen.

Set the spoke ends together. Hold the inner cone of the flame about $^1/_4$ to $^1/_2$ in. away from the rim and heat the spoke and a small area of the rim. The inner cone is the small white part of the flame at the end of the welding head. At the same time heat the end of the

C. H. Wanamaker is connected with The Linde Air Products Co., New York.

* Bronze welding is also called braze welding.

*Fig. 1 Clean the spoke ends and inside of the rim with a file or steel wool*

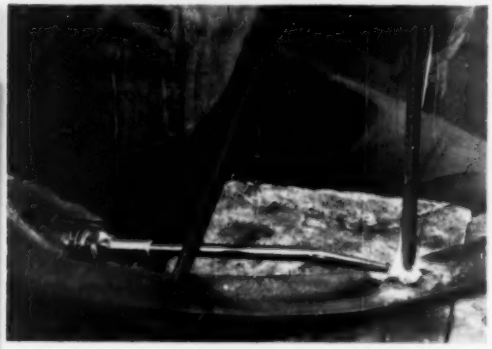


*Fig. 2 When the rod tins properly, form a puddle about the size of a dime*

welding rod and dip it into the flux. When the rod is hot the flux will stick to it.

The heated spot on the rim should be about as big as a half dollar with the spoke at its center. Direct the flame at the end of the loose spoke and the end of the spoke still attached to the rim. When the rim and the spoke ends turn a dull red, you are ready to weld. Place the welding rod on the heated spot where the spoke ends meet. The flame will melt the rod, and the bronze will flow smoothly onto the heated spoke ends and the rim. This is called tinning.

If the metal is too hot the molten bronze will boil and roll around like water on a hot stove. A gray

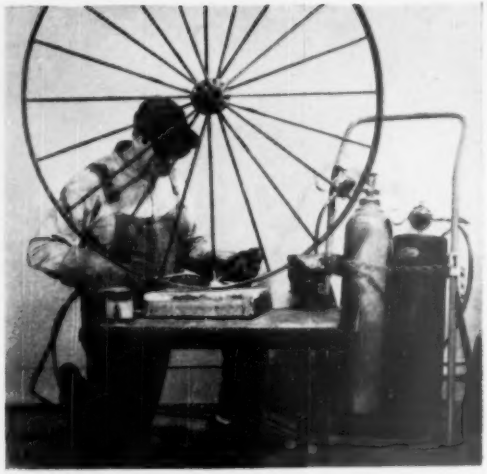


*Fig. 3 Deposit enough welding rod metal to join the spoke ends and to let weld metal flow onto the rim*

smoke coming from the bronze indicates that it is burning. Draw your blowpipe back several inches, let the metal cool slightly and melt the rod again. If the molten bronze forms small balls and does not tin, the rim is too cool. Move the flame closer and get more heat in the metal. The bronze will not tin properly if the metal has not been cleaned properly.

When the rim and spoke ends tin, hold the end of the welding rod against the spoke. The rod will melt and form a small puddle. Keep the rod in the puddle and move it in small circles to get weld metal on the spoke.

Move the blowpipe and rod slowly around the spoke and keep adding molten metal from the rod. Be sure that the spoke ends and the rim are at the proper temperature before the molten metal flows on to them. If your welding rod sticks in the puddle do not jerk it loose, just melt it loose with the flame. The job is finished when you have circled the spoke and joined the spoke ends. Weld metal will flow onto the rim and serve as reinforcement. Clean off the flux with a file or wire brush.

When a casting breaks in two or more pieces repairs can be made by butting the pieces together and making the weld. Here is an example of a job that was done

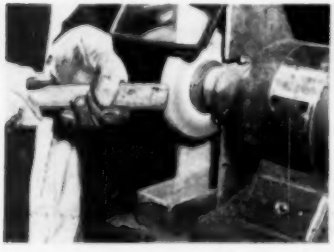


*Fig. 4 Here the operator is beveling a broken machine part*

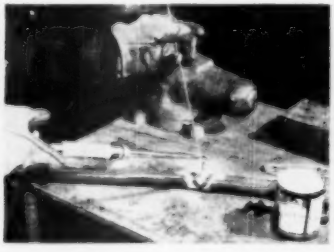


*Fig. 5 When you get good tinning, form a puddle and add welding rod*

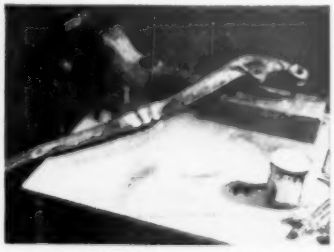


*Fig. 6 Make the same weld on the other side. Here is the finished job*

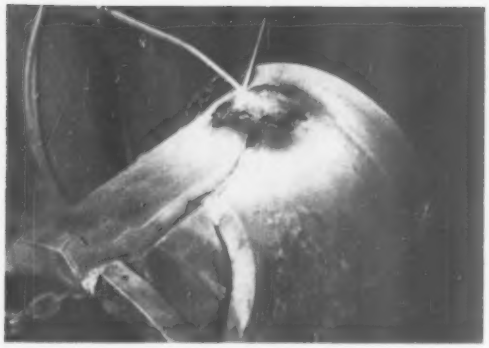


*Fig. 7 When there are several broken pieces, make tack welds to hold them in position*

that way. This is also an example of a job that needed a bevel because it is more than $^1/_8$ in. thick.

Bevel the edges on a thick part like this on both sides for about $^1/_2$ the thickness with a file or on your grinding wheel. This will leave metal in the middle. Because this is cast iron there is also another prewelding job. After you grind the surfaces, heat them to a dull red with your blowpipe. When they cool slightly, go over them with a wire brush. Clean the metal around the break for about 1 in. on each side.

Fit the broken ends together and support them so they do not sag. Connect a medium-size welding tip to your blowpipe and again adjust the flame so that it has a slight excess of oxygen. Heat the metal on both sides of the break until it turns very dark red. Then put the end of the welding rod on the hot metal and start to melt the bronze welding rod. Do not forget to dip the heated rod end in the flux can first.

If you did a good cleaning job the molten metal will flow smoothly onto the heated metal and down into the vee like water on clean glass. Of course you must watch the temperature of the metal too. If it is too hot, the molten bronze will boil and if it is too cool the bronze rod will form small drops. Draw the flame back or come closer to the work to get the right tinning action but do not melt the casting.

When the molten bronze starts to tin, keep adding welding rod to the puddle until the weld is slightly higher than the surface of the work. Let the rod metal get on the surface for about $^1/_2$ in. on each side of the vee. Notice that the flame melts the welding rod, and keeps the puddle at the right temperature. It also preheats the metal ahead of the puddle and prepares it for tinning.

When the weld metal has been built up, start to move the blowpipe forward slowly. Raise and lower the blowpipe flame to keep the work and puddle at the proper temperature. You will notice that the metal ahead of the puddle tins automatically when it is at the right temperature. When you add welding rod, keep the rod in the puddle. Continue to add molten welding rod and build up the weld along the vee. Turn the work over and make the same kind of weld on the other side. Support the work so that it will not sag or shift when you weld the second side.

This job shows a repair that required a weld of only $1^1/_2$ to 2 in. When the break is longer, and it sometimes might be 12 in. or more, you will need a tack weld at the beginning of the break and another at the end of the break. Figure 7 shows how tack welds will hold the parts in proper alignment. On large parts use your blowpipe or a furnace to preheat the broken sections and reduce the amount of spreading that will take place in the break. Start the weld at the most internal point and work toward an edge.

It has been found that when dirty greasy cast iron has been ground, some of the oil penetrates into the casting. This hinders the tinning action of the bronze and makes for porosity. This can be greatly eliminated by painting the casting after it has been prepared and right ready for brazing with c.p. hydrochloric acid (obtainable in any drugstore). After the acid eats on the metal for 15 min., scrub with wire brush and cold clean water. After the acid has been rinsed off, start the brazing operation in the usual way and one will be surprised how much easier the bronze will adhere. Might say, too, when the acid is applied by paint brush or cotton on welding rod, acid will boil out oily substance just like peroxide on a cut or sore.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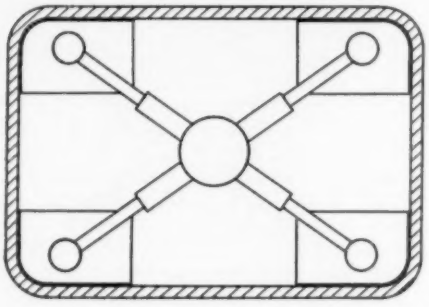
# Internal Expanding Jig for Sheet Metal Stamping

THE internal expanding jig shown in Fig. 1 is used to hold sheet-metal stampings while they are being welded. The jig consists of two parts: the pistons with cast-iron blocks, shaped to fit the internal contour of the stamping, and a cast-iron cover which fits over the stamping to prevent distortion and movement of the stamping during the welding. The pistons which are mounted on a central pedestal may be controlled pneumatically, hydraulically or by means of simple screws. When a stamping is placed on the jig, the pistons are contracted and the stamping set in place. The pistons are then expanded and hold the stamping firmly in place. A contraction and expansion of $^1/_2$ in. is usually enough to allow the stampings to be removed and replaced.



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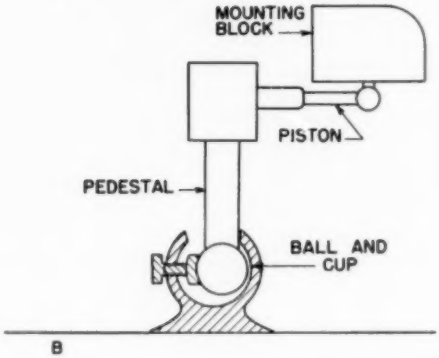


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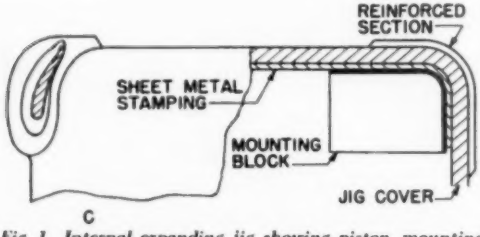


C

*Fig. 1 Internal expanding jig showing piston, mounting blocks, cover and pedestal*

Sketches and data courtesy of Air Reduction Sales Co., New York, N. Y.

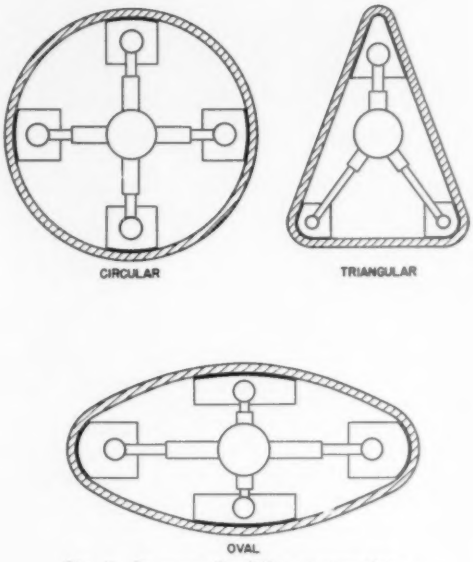


*Fig. 2 Jig set up for different stampings*

To prevent distortion and movement of the stamping during welding, a heavy jig cover of cast iron is made to fit over the stamping to hold it in place during the welding. At the locations were the welds are made, the cover is reinforced and openings made for access of the welding tools.

In using this type of jig, the mounting blocks should always be located at the natural corners of the stampings. This should be planned when the stamping and mounting blocks are designed. If this is impossible and welds must be made on the stamping in spots that are not backed by the mounting block, additional backing must be provided at these locations. The illustrations in Fig. 1 show the jig used on a rectangular stamping. However, by changing the shape of the

mounting block, the position of the pistons, and the form of the cover, it is possible to use the same type of jig for other stampings. Figure 2 shows the jig set up for circular, oval and triangular stampings.

If it is desirable that the jig and cover be tilted to facilitate welding, a universal ball and locking arrangement may be installed at the bottom of the pedestal Fig. 1(*B*). By turning the locking handle at the base of the pedestal and allowing the ball to rotate in its cup, the pedestal may be tilted in any direction. When the pedestal is tilted in the desired direction, the handle is tightened and holds the pedestal in position.

# Stove and Furnace Repairs

*by M. S. Casson*

SLAMMED furnace doors, jammed clinkers, dropped shakers—all mean trouble for the home owner. Of course, stove and furnace parts break only during the winter when heat is needed. That is where the welding shop can step into the picture, because most stove and furnace parts can be repaired by this method.

When you repair stove or furnace parts remember that if the parts come in contact with the fire, such as grate bars, you must fusion weld with cast-iron welding rod. Parts such as shaker bars, stove bases, oven doors or door lugs that are not touched by the fire can be braze welded. Here are several typical jobs that should help you to do similar repairs.

Figure 1 shows a stove base being braze welded. The crack was in a very thin section at the ash door. First the area was carefully wire brushed. Then, a three-cornered file was used to make a deep vee at the smooth edge where the door closes. In the figured metal the bronze welding rod was deposited in a thick layer to provide extra reinforcement. The vee was filled in and then filed smooth so the door could close.

Figure 2 shows a draft door lift arm that was repaired by braze welding. A small vee was ground on the broken part and as part of the cleaning job the metal was heated to a dark red and allowed to cool. This is always done before braze welding cast iron when the edges have been prepared by filing or grinding. The broken part was positioned and tack welded before the final weld was made. On a part like this it is not necessary to file down the excess weld metal because it acts as reinforcement.

**M. S. Casson** is with The Linde Air Products Co., Philadelphia, Pa.

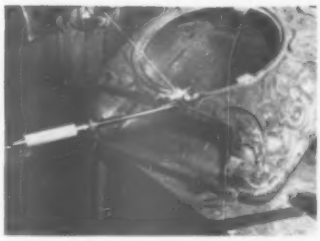

*Fig. 1 Here is a stove base being braze welded. A three-cornered file was used to make a vee at the crack*

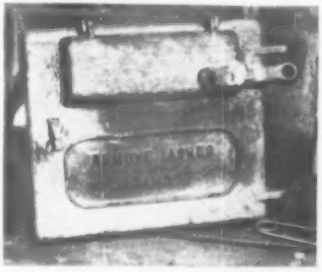

*Fig. 2 On a small part, like this draft door lift arm, excess weld metal acts as reinforcement. Do not file it off*

*Fig. 3 When you weld a grate bar, fusion weld it and use plenty of flux. You can skim impurities from the surface of the puddle with your welding rod*

The grate bar, shown in Fig. 3, is an example of a part that must be fusion welded with cast-iron welding rod. That is because it will be heated by the fire and a braze-welded repair would be melted out. To make a repair like this, bevel and clean the broken edges to remove all scale and rust down to the base metal. It is important to do a good cleaning job because careless cleaning will probably produce porous spots and blowholes in the weld. Match the broken pieces together and hold them in position with firebrick, welding paste or one of your shop work-holding devices.

Use a slightly larger flame than you would use on new cast iron of the same thickness. Keep the inner cone of the flame from 1 to 2 in. from the surface and let the heat soak deep into the metal. Sprinkle a generous amount of cast-iron welding flux in the weld area while you are preheating. You will find that it is almost impossible to melt the metal when the grate bar has been used for even a short time. When the metal at the fracture appears oily under the flame add molten metal from the welding rod. You will get what amounts to a tinning action, just as you do in braze welding.

When the surfaces of the grate have been "tinned" proceed as though you were doing any cast-iron welding job. Dip the rod in the flux often and continue to add welding rod until the weld metal is about $^1/_8$ in. higher than the surface of the grate bars. If gas bubbles or white spots appear on the puddle or at the edges, add flux and direct the flame around the speck until the impurities rise to the top. Then skim them from the weld with the end of your welding rod. Tap the rod on the table to remove any impurities that stick to the rod.

Clean the weld and grind it if necessary, but leave as much weld metal as possible to act as reinforcement.

# the AMERICAN WELDING SOCIETY

## activities • related events

### Member for Member Drive

The AMERICAN WELDING SOCIETY has launched a new Member for Member Drive. This is the first time in many years that every Member of the WELDING SOCIETY has had the opportunity to officially assist in the campaign to secure new members. This drive is designed to secure a type of membership which will result in the greatest benefits to the SOCIETY and the industry. Every member undoubtedly has at least one friend or acquaintance who would profit from affiliation with the AMERICAN WELDING SOCIETY. To launch this drive President O. B. J. Fraser has sent a letter to every member of the SOCIETY enclosing a brochure highlighting the advantages of membership in the SOCIETY. This folder contains a simple application blank on the back. Every member securing a new member should be sure that his name is included as a proposer. In this way, credit will be given through publication in THE WELDING JOURNAL. Although the letter has been recently sent out, returns already available assure the success of this campaign.

### Third Edition of the Welding Handbook

Publication of the *Third Edition of the Welding Handbook* has just been announced by the AMERICAN WELDING SOCIETY. This book, which has been recognized as the most complete and authoritative source of information on welding, represents more than four years of effort and the experience of more than 250 experts who have contributed their personal knowledge and experience and the knowledge, experience and results of research of their companies and many others in their respective fields.

No effort has been spared in providing useful up-to-date information in readable form. The *Handbook* is intended to be equally useful as a text on welding and as a reference book. Suggestions obtained from a nation-wide survey of users of the earlier editions have been incorporated to provide the data most needed by the welding industry.

Twenty-seven chapters are devoted to the more than 30 welding and cutting processes used in industry today. Information on each process covers the equipment used, the basic principles of operation and the application of the process for different metals and different industrial applications.

Thirteen chapters contain information on the ferrous and nonferrous metals commonly welded, including their general properties, how to weld them with the different welding processes and their use by different industries. Metals covered include iron, wrought iron, carbon and low-alloy steels, chromium steels, chromium-nickel steels, manganese steels, aluminum, magnesium, copper and nickel and their alloys, lead, zinc, clad steels and applied liners.

A group of eleven chapters contains information on design, material, workmanship and inspection requirements for industrial applications such as aircraft, bridges, buildings, railroads, storage tanks, pressure vessels and boilers, ships, automotive products, pipe lines, industrial piping and machinery.

Additional individual chapters are devoted to data for estimating costs, physics of welding, welding metallurgy, a dictionary of welding terms and definitions, general engineering tables for shop and office use and welding standards, including welding symbols, filler metal specifications and standard tests for welds.

The Third Edition of the *Welding Handbook* contains several features which are intended to make it more useful for ready reference: the arrangement of the text in each group of chapters, i.e., metals, processes and applications, is the same in so far as possible so that the reader might expect to find the same type of information in the same relative location in each chapter within any one group. The more than 300 tables included in the *Handbook* contain reference data on welding procedures, properties of metals, properties of welds, code requirements and test results. The 69-page index makes it possible to readily find specific information and related information contained in different chapters. Both the index and the text itself are extensively cross referenced. Items in the index have been grouped by welding processes, by metals, by applications and have been further grouped by the common divisions of engineering such as design, workmanship, inspection, etc. Each item is also separately listed in alphabetical order.

The format of the *Handbook* is new. Each page is set in two columns which makes the book easier to read according to authorities who have studied reading habits. The book is profusely illustrated with sketches and photographs of welding equipment, welding details and specific applications. A bibliography is included at the end of each chapter listing the important codes, standards, books, and technical articles on the subject of the chapter for those seeking further information.

The third edition of the *Welding Handbook* should be useful to anyone in any way connected with welding whether as a welding engineer, welding foreman, salesman, welder, designer, purchasing agent, inspector, manufacturer of welding equipment or user of welded products.

Copies of the *Welding Handbook*—which contains 1650 pages, is cloth bound, illustrated, and indexed—may be obtained from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. The price per copy is $12 in the United States and Canada, $13 elsewhere.

### Mid-Southern District Sets Record

The Mid-Southern District has achieved the distinction of being the first district of the SOCIETY in which 100% of the Local Sections have appointed Technical Representatives. Under the usual active leadership of their District Vice-President, R. L. Townsend, this District now leads the field in better providing its membership with assistance in solving their welding problems.

If your Section does not have a Technical Representative then you are not getting the full benefit of your membership in A.W.S. By appointing a Technical Representative you will be providing your Local Section with a channel through which you will be regularly informed of new technical developments and new A.W.S. Standards. For complete details Section officers should write to S. A. Greenberg, Technical Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

### Journal Questionnaire

Every member of the AMERICAN WELDING SOCIETY received a copy of the questionnaire prepared by the Welding Journal Committee. It is extremely important that each member fill in and return this questionnaire so as to reflect his own personal desires with reference to the JOURNAL.

This is not a case of "winner take all." The Welding Journal Committee and the Editor are guided by the results of the questionnaire. The amount of material published generally is in proportion to the interest indicated in the particular section

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### Microfilm Service

The AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y., has entered into an agreement with University Microfilms, Ann Arbor, Mich., to make available to the libraries issues of THE WELDING JOURNAL.

One of the most pressing problems facing all types of libraries today is that of providing adequate space for a constant flood of publications. Periodicals pose an especially difficult problem because of their bulk and number.

Microfilm makes it possible to produce and distribute copies of periodical literature on the basis of the entire volume in a single roll, in editions of 30 or more, at a cost approximately equal to the cost of binding the same material in a conventional library binding.

Under the plan, the library keeps the printed issues unbound and circulates them in that form for from two to three years, which corresponds to the period of greatest use. When the paper copies begin to wear out or are not called for frequently, they are disposed of and the microfilm is substituted.

Sales are restricted to those subscribing to the paper edition, and the film copy is only distributed at the end of the volume year.

The microfilm is in the form of positive microfilm, and is furnished on metal reels, suitably labeled. Inquiries concerning purchase should be directed to University Microfilms, 313 N. First St., Ann Arbor, Mich.

## $2250 in Prizes for Papers on Resistance Welding—Design, Application and Research

***Prizes and Contest Rules***

Announcement has been made of cash prizes to be awarded in 1950 by the Resistance Welder Manufacturers' Assn., 505 Arch St., Philadelphia, Pa., for outstanding papers dealing with resistance welding subjects. The total amount of the awards is $2250, and a wide choice in subject matter is allowed in order to assure eligibility to all papers which cover worthwhile and significant achievements in the field. The contest judges will be appointed by the AMERICAN WELDING SOCIETY, and awards will be made at the 1950 Fall meeting of the SOCIETY. Contest closes July 31, 1950. The prizes and rules governing the contest are as follows:

One prize of $750 for the best paper emanating from an industrial source, consulting engineer, private or government laboratory, or the like, the subject matter of which is concerned specifically with resistance welding. There are no restrictions on the scope of the subject matter. For example, it may be devoted to redesign of a product or products for resistance welding, improvement (from a welding and cost viewpoint) in a present design for resistance welding, resistance welding research, development of new procedures to broaden the field of application of resistance welding, etc. Papers in these categories should explain the economic importance of the accomplishments described—that is, cost savings, production improvement, scope of application, etc.

A prize of $500 for the second best paper in the above classification. A prize of $250 for the third best paper in the above classification.

A prize of $300 for the paper emanating from a University source (the author of which is either an instructor, graduate student or research fellow) which in the opinion of the Board of Award is the greatest original contribution to the advancement and use of resistance welding from this source.

A prize of $200 for the second best paper in the above classification.

A prize of $250 for the paper emanating from a University source (the author of which is an undergraduate student) which in the opinion of the Board of Award is the greatest original contribution to the advancement of resistance welding from this source.

The contest is open to anyone, without restriction, from the United States, its possessions and Canada. It is also open to any member of the AMERICAN WELDING SOCIETY in any grade from any place in the world. The contest is considered as having opened Aug. 1, 1949. In order to be eligible for this contest all papers must be forwarded so as to be delivered at AMERICAN WELDING SOCIETY headquarters no later than 5:00 P.M., July 31, 1950. Papers which are to be presented at the Annual Meeting of the AMERICAN WELDING SOCIETY in October may also be entered in this contest, in which case a draft or copy of the paper must be filed with the AMERICAN WELDING SOCIETY not later than July 31, 1950. To be eligible, author must indicate paper has not been considered previously in the contest, or shall not have been presented or published elsewhere.

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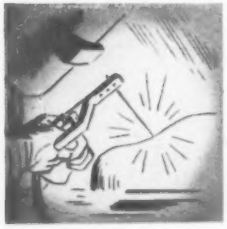

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HAYNES Alloy 92: A moderately low melting point rod. Use it on thin sections where low-temperature deposition is necessary to prevent distortion and on large parts when preheating is difficult or impossible. Deposits have a hardness of Rockwell C 65.

HAYNES Alloy 93: Gives excellent service where high cold-hardness is necessary. It is suitable for applications involving abrasion from sand, gravel, mill scale, or other hard particles.

HASCROME Rod: A work-hardening rod, recommended for use under conditions of severe impact. It is widely used for hard-facing rock and earth handling equipment parts. Recommended for electric application to manganese steel.

## HAYNES Tungsten-Base Alloys

HAYSTELLITE Cast Tungsten Carbide: The hardest of all HAYNES hard-facing alloys, used where utmost resistance to abrasion is required. Typical applications include oil-well drilling tools, ditcher teeth, and coal undercutter bits.

## HAYNES Nickel-Base Alloys

HASTELLOY Alloy C: Recommended for building up wearing surfaces of hot-working steel mill parts such as hot shear blades, entry guides, and shafts.

HAYNES alloys
TRADE-MARK

The trade-marks, "Haynes," "Haynes Stellite," "Hascrome," "Haystellite," "Hastelloy," and "Heliarc" distinguish products of Union Carbide and Carbon Corporation or its Units.

**Haynes Stellite Division**
**Union Carbide and Carbon Corporation**
UCC
**General Offices and Works, Kokomo, Indiana**
**Sales Offices**
**Chicago — Cleveland — Detroit — Houston**
**Los Angeles — New York — San Francisco — Tulsa**

where prior to its appearance in THE WELDING JOURNAL.

All papers submitted in the contest become the joint property of the R.W.M.A. and the AMERICAN WELDING SOCIETY, who will retain all rights thereto. The AMERICAN WELDING SOCIETY will appoint five judges, who will judge the relative merits of the various papers submitted and make the awards accordingly. The decision of the judges will be final.

For the author or authors to be eligible for this award, the paper shall describe clearly original work done by them or under their supervision on resistance welding in any of its aspects by any method or process. The paper shall be a full disclosure of the subject. The paper shall contain no statement which is unethical advertising or sales promotion. The paper may contain statements of fact, including the names of either individuals or organizations of any kind, commercial designations, trade names, etc. The minimum length requirement is 2500 words.

All papers must be typewritten, double spacing, written on one side only of blank white paper. Photographs, charts, graphs, etc., may either be attached directly to the copy or may be detached, in which case they should be clearly identified with figure numbers, captions, etc.

Papers entered in this contest should be sent to AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. If mailed to arrive not later than July 1, 1950, three copies should be furnished. If mailed to arrive between July 1 and July 31, 1950, six copies should be furnished.

## Board of Directors Meeting

A Board of Directors meeting of the AMERICAN WELDING SOCIETY was held in the Headquarters Room of the Hotel Statler, New York City, at 10:00 A.M. on Thursday, Dec. 15, 1949, with the following present:

*Members:* O. B. J. Fraser, *Chairman*, D. Arnott, L. C. Bibber, R. S. Donald, J. Grodrian, H. O. Hill, J. H. Humberstone, T. M. Jackson, C. H. Jennings, C. I. MacGuffie, A. J. Moses, F. L. Plummer, L. C. Stiles and J. B. Tinnon.

*By Invitation:* T. J. Crawford, Chairman, A.W.S. Detroit Section, D. Joseph, A.W.S. Auditor, A. G. Oehler, Chairman, THE WELDING JOURNAL Committee.

*Staff:* J. G. Magrath, F. J. Mooney and W. Spraragen.

*Results of Letter Ballot Regarding Adoption of Cautionary Wording for Use on Labels of Fluoride-Bearing Fluxes*

President Fraser announced the results of letter ballot sent to the Board of Directors concerning the adoption of cautionary wording for use on labels of fluoride-bearing fluxes. He stated the results were as follows: Approved, 15; Did Not Approve, 6; No Reply 6.

*Approval of Minutes of September 22, 1949, Board of Directors Meeting*

The minutes of the Sept. 22, 1949, Board of Directors Meeting were approved, as circulated, with adjustment as follows:

Rule 6 of Rules to Govern Organization, Functions and Operations of Technical Committees of the AMERICAN WELDING SOCIETY was amended to read: "After a majority of the members have accepted appointment, the temporary chairman of the technical committee shall take immediate steps to elect permanent officers and to initiate the work of the committee."

*Results of Letter Ballot on Proposed AWS By-Law Amendments*

The Secretary announced that by-law amendments as approved by the Executive Committee on Mar. 7, 1949, by the Board of Directors on May 13, 1949, and by the voting membership on Nov. 15, 1949, indicated that of the 1073 membership returns, 977 approved all amendments without comment; 20 approved all amendments with comment; 33 voiced disapproval, some with all amendments and others on certain amendments; 34 were doubtful, i.e., some indicated both approval and disapproval while others signed the ballot but did not check; and 9 were received without signature.

In that less than a 20% rejection to the amendments was received, in accordance with the by-laws the amendments stand approved as submitted to the membership.

*University Microfilms Granted Right to Reproduce Certain A.W.S. Publications in Microfilm Form*

University Microfilms of Ann Arbor, Mich., extended an invitation to A.W.S. to grant them the right to reproduce A.W.S.


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Carbide
IN THE RED DRUM

EFFICIENT
ECONOMICAL
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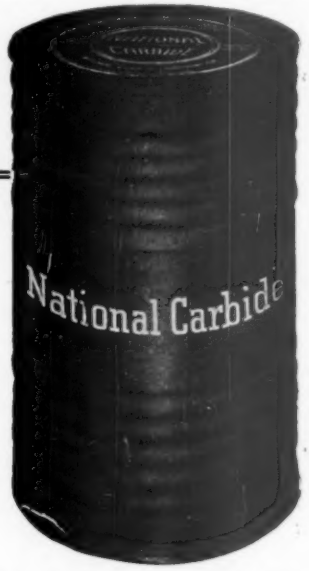


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Use National Carbide in the Red Drum
Write us for information as to nearest available stock.
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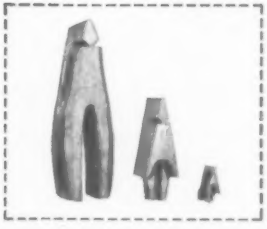
*the fast, low-cost way to get worn teeth back in service!*

1. Worn tooth . . . 2. Plus AMSCO Tooth Repointer . . . 3. Equals like-new tooth—ready for service!

# AMSCO® tooth repointers



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3 teeth partially rebuilt with AMSCO Repointer Bars to show sectional view of welding method. These Repointer, or Wedge Bars, are also made in many shapes and sizes. Apply AMSCO Economy Hardface to the rebuilt tooth *—for as much as 3 times longer service!*

● Here's a typical example of a badly worn dipper tooth completely restored to service . . . simply by welding on the AMSCO Cast-To-Size Tooth Repointer. The result is like-new service life and efficiency, plus a long-wearing tooth of Manganese Steel—the steel that actually work-hardens in service. Cost? *Far less than replacement!*

Wherever equipment has teeth that wear, more and more owners are using money-saving AMSCO Tooth Repointers . . . available in a wide variety of styles and sizes.

**Get all the facts! Write today for Bulletin W-10-A —showing complete instructions for use.**

*put LIFE into service with*

**AMSCO®**
WELDING PRODUCTS

AMERICAN Brake Shoe COMPANY

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399 EAST 14th STREET • CHICAGO HEIGHTS, ILL.

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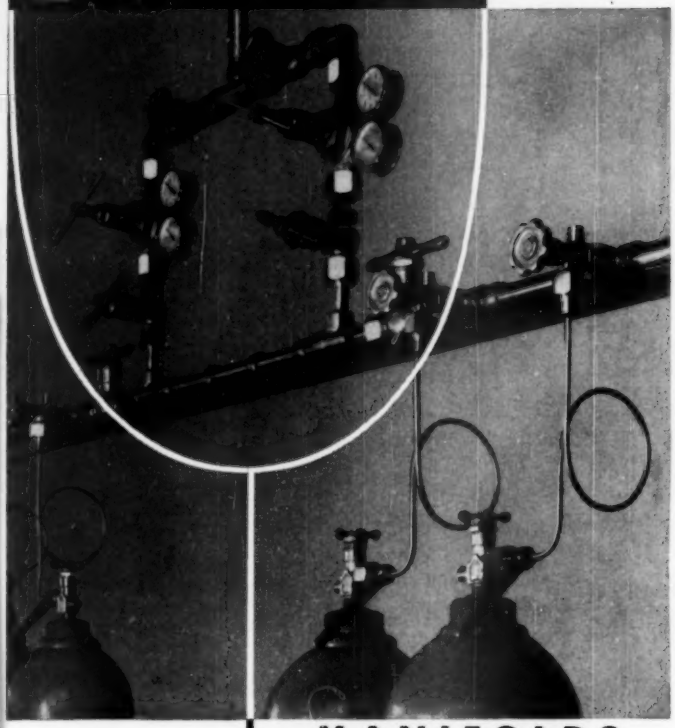

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OXYGEN
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and other high pressure gases

*Write for 24 page catalog giving complete specifications.*

Rugged construction and precision control equipment give RegO manifolds long life, safe performance and low maintenance.

**Continuous Operation . . .** Shut-off valve at each cylinder station permits removal of any cylinder without shuting down entire side of manifold. Master valves control each bank of cylinders.

**Unit Construction . . .** Header consists of steel I-beam, extra heavy brass pipe and fittings, cylinder station and master shut-off valves . . . *with all permanent connections silver brazed.*

**Precision Regulation . . .** Uniform delivery pressure is assured by dual large capacity two-stage RegOlators.

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Pioneer and Leader in the Design and Manufacture of Precision Equipment for Using and Controlling High Pressure Gases

publications in microfilm form. In consideration for this right, University Microfilms agrees to extend A.W.S. a royalty of 10% of the sale price of each microfilm copy sold.

The Board of Directors voted to grant University Microfilms the right to reproduce A.W.S. publications and instructed the Secretary to accordingly inform this group of the Board's decision.

*I. B. Hexter Appointed to* THE WELDING JOURNAL *Committee*

A. G. Oehler, Chairman of THE WELDING JOURNAL Committee, requested the appointment of I. B. Hexter to that Committee. Mr. Oehler stated that Mr. Hexter can greatly help the work of this Committee, if appointed.

The Board of Directors approved the appointment of Mr. Hexter to this Committee.

*Acceptance of Report of Minutes of Finance Committee Meeting Held on Dec. 9, 1949*

A review of the minutes of the Finance Committee Meeting held on Dec. 9, 1949, indicated the following major items of interest:

(1) A $50 (cost of which will be $37.50) U. S. Savings Bond to be awarded by THE WELDING JOURNAL Committee to the A.W.S. member returning the most helpful answer as to his opinion on recent changes made in THE WELDING JOURNAL.

(2) Payment of travel and sales promotion expenses to A.W.S. advertising agency, The Kotula Co., for the month of January 1950. Previous ruling included payment only until Dec. 31, 1949.

(3) Purchase of both an addressograph and graphotype machine for office use. These machines will cost $2509.30, less $85 trade-in allowance on present machines.

(4) Finances of SOCIETY do not allow grant of request from the Institute of Welding for A.W.S. donation to their Working Reserve Fund.

It was voted that the Secretary assume responsibility for and be in charge of JOURNAL advertising solicitation in the event of severance of relationship with The Kotula Co. It was recognized that this is but a temporary measure and will be subject to change as soon as the JOURNAL advertising and the SOCIETY's financial condition warrant a change. The JOURNAL Editor is to be charged with the responsibility of maintaining records of contracts, files, etc., for which his Department is currently responsible.

*New A.W.S. Sections Officially Organized*

The Secretary reported that the following A.W.S. sections have been officially organized on dates as indicated:

| *Name of Section* | *Location* | *Date Organized* |
|---|---|---|
| Salt Lake City | Salt Lake City, Utah | Sept. 30, 1949 |
| Eastern Illinois | Danville, Ill. | Oct. 14, 1949 |
| Susquehanna Valley | Berwick, Pa. | Oct. 14, 1949 |
| Richmond | Richmond, Va. | Dec. 1, 1949 |

# WELDING MONEL?

## Which electrode do you need...

Both the "140" and "130X" electrodes are used for welding Monel®, but each of these rods is designed to do a specific job.

For best results... sound, strong, corrosion-resistant welds... it pays to make sure you have the right rod for the job at hand.

Check the following table carefully when in doubt ... and file it for future reference!

| QUESTION | • "140" ELECTRODE | • "130X" ELECTRODE |
|---|---|---|
| 1 Which rod is right for welding solid Monel in all positions? | May be used if no "130X" is at hand. | Best |
| 2 Which rod for overlaying Monel directly on steel? | Yes | No. A barrier layer of nickel must first be laid down. |
| 3 Which for joining wrought or cast Monel to steel or stainless steel? | Yes | No |
| 4 Making direct Monel-to-steel welds? | Yes | No |
| 5 Joining Monel to nickel? | Yes | Best |
| 6 What are the recommended amperages? | 3/32" 35-60 amp.<br>1/8 " 70-110 amp.<br>5/32" 110-150 amp.<br>3/16" 140-190 amp. | .075 " 25-40 amp.<br>3/32" 45-60 amp.<br>1/8 " 60-95 amp.<br>5/32" 80-150 amp.<br>3/16" 140-190 amp.<br>1/4 " 170-260 amp. |
| 7 What type of current and polarity must be used? | D.C. Reversed polarity. | D.C. Reversed polarity. |
| 8 Are the corrosion-resisting properties of the weld deposit comparable to those of the parent metal? | Yes | Yes |
| 9 Do the mechanical properties of the weld deposit compare with those of the parent metal? | Yes, assuming parent metal is in the soft-temper condition. | Yes, assuming parent metal is in the soft-temper condition. |

### NEW PACKAGING NOW STANDARD

All Inco welding electrodes are now supplied in special moisture- and shock-resistant tubular containers.

* * *

For a permanent addition to your reference files, ask for your copy of Technical Bulletin T-2, *The Welding, Brazing, and Soldering of Monel, Nickel, and Inconel®.*

EMBLEM OF SERVICE INCO TRADE MARK

**THE INTERNATIONAL NICKEL COMPANY, INC.**

*67 Wall Street, New York 5, N. Y.*

# Q. CAN YOU HEAT A HIGH PRESSURE, WELDED PIPE JOINT TO 1700° F, 30 FEET UP IN THE AIR?

# A. The Smith Dolan System can EASILY handle this problem of Preheating Stress Relieving and Normalizing to 1700° F on Carbon and Stainless Steels!

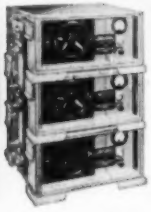
*Boiler down-comer partially wrapped for stress relieving.*

**1. SAFE TO USE EASILY APPLIED ASSURED RESULTS** — Smith Dolan Heating Apparatus is so simple to handle that it can be operated by job personnel. Because it delivers consistently perfect results under safe conditions, it assures you of minimum job cost.

**2. THOROUGH PENETRATION** — It is no problem to achieve thorough heating of heavy sections with precise control in minimum time.

**3. MEETS METALLURGICAL & CODE REQUIREMENTS** — Proper heating is delivered according to set specifications and requirements of Boiler and Piping codes.

**4. LABORATORY CONTROL UNDER FIELD CONDITIONS** — Smith Dolan Induction Heating Apparatus is designed and engineered with automatic or semi-automatic controls. Therefore, you obtain accurate, consistent results under field conditions, with a permanent record of each job always available.



***NEW MODEL U-P*** — *Patented Smith-Dolan System, portable, low frequency induction heater, three-high stack (shown) 30 kva—10 kva per unit. Buy one or stack 2 or 3 for increased capacity. Buy what you need —build as you go.*

***INDUCTION CONTROL CABINET*** *used with Model U-P units (shown) and Model GC Duplex 120 or 150 kva induction heaters (shown in catalog).*

**ELECTRIC ARC** can supply equipment for ANY TYPE OF JOB—equipment that can be *purchased outright or rented*. From what other source could you possibly obtain such wide latitude in planning for every job in preheating and stress relieving before welding and normalizing? Today, more than ever, Electric Arc equipment is specified where other methods are too costly or impractical. Write for informative catalog.

ELECTRIC-ARC INC.

**ELECTRIC-ARC, INC.**
161 JELLIFF AVE., NEWARK 8, N. J.
*Welding Equipment, Electrodes & Supplies*


*Establishment of Advisory Committee of A.W.S. Past Presidents*

After discussion the Board of Directors upon motion, duly seconded, voted the establishment of an Advisory Committee of A.W.S. Past Presidents and to consist of all living A.W.S. Past Presidents and for this Committee to elect a Chairman who will serve for a one-year term. Membership in this Committee is for life.

*Approval of President's Selection of 1949–50 National Nominating Committee Personnel*

President Fraser submitted to the Board of Directors for approval his selection of personnel to serve on the 1949–50 National Nominating Committee. President Fraser stated that he requested each District Vice-President to submit three names of potential members from his district, preferably not more than one from any section. Such was done and after carefully reviewing the personnel selected by the President, the Board of Directors upon motion, duly seconded, voted favorably for appointment to the 1949–50 National Nominating Committee the following candidates as submitted by President Fraser:

H. C. Boardman, Chicago Bridge & Iron Co., Chicago, Ill., Chairman; L. C. West, Empire Structural Steel Fabricators, Inc., Syracuse, N. Y.; C. A. Loomis, Bureau of Ships, Navy Dept., Washington, D. C.; A. E. Pearson, Ingalls Iron Works Co., Birmingham, Ala.; J. F. Maine, Republic Structural Iron Works, Cleveland, Ohio; R. L. Kohlbry, Machinery & Welder Corp., Chicago, Ill.; J. Fiegener, The Boardman Co., Oklahoma City, Okla.; and H. E. Rhoades, National Cylinder Gas Co., San Francisco, Calif.

*E. C. Smith Appointed to Public Relations Committee*

H. F. Reinhard, Chairman of the Public Relations Committee, requested the appointment of Earl C. Smith to that Committee.

The Board of Directors unanimously approved the appointment of Earl C. Smith to this Committee.

*Membership Status Report for Three-Month Period Ended Nov. 30, 1949*

The Assistant Secretary reported that for the three-month period Sept. 1, 1949 to Nov. 30, 1949, the SOCIETY reported a gain of 424 members as against a loss of 351 members, resulting in a net gain of 73 members. The total A.W.S. membership as of Nov. 30, 1949, was 7264 members.

During the first 14 days in December, the SOCIETY had enrolled 101 new members and 90 delinquent members have remitted payment of dues.

*Decline in Membership Delinquency*

The Secretary observed that as of Nov. 30, 1949, the SOCIETY's delinquency was 15.7% as against 20.5% on Nov. 30, 1948.

*Organization of A.W.S. Sections in South America*

A prominent member in Argentina has requested information on procedure for starting an A.W.S. section in that coun-

WELDING CONNECTORS
Saxe System Welded Connection Units
for welded assembly

*Saxe Units* place in position and securely hold together structural parts to be welded.
As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.
"Write for 58 pg. Manual containing full engineering design information for welded structures."
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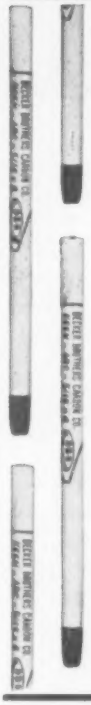
NET MONTHLY ADVERTISING RATES
Black and White — Effective July 11, 1947

| Space | One Insertion | Three Insertions | Six Insertions | Twelve Insertions |
|---|---|---|---|---|
| *Full page | $185 | $165 | $150 | $140 |
| Two-thirds page | 130 | 120 | 110 | 100 |
| Half Page | 105 | 95 | 85 | 80 |
| Quarter Page | 60 | 58 | 55 | 50 |
| Eighth Page | 40 | 35 | 30 | 28 |
| *Inside Preferred | 205 | 185 | 170 | 160 |

10% Extra for bleed full pages. Color $65 extra per color added
Agency Commission —15%
Cash Discount — 2%, 10 days



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A complete line of Welding Brushes for ALL types and makes of Welding Equipment—Keen-Arc Carbons (illustrated) for twin-arc torches—carbon and graphite welding electrodes —carbon rods, plates and paste—a complete line of replacement brushes for all motors and generators... plus the facilities and engineering staff to produce any electrical or mechanical carbons to your specifications. Write for catalogs.

BECKER BROTHERS CARBON CO.
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CARBON


try. He advises that the American Society for Metals recently organized a section in Argentina.

President Fraser tabled this item for discussion of the next meeting of the Executive Committee of the Board of Directors.

*Greater Publicity Needed for Annual Business Meeting*

The Secretary stated that in the past very little publicity has been accorded the Annual Business Meeting of the SOCIETY. The attendance has been small and more frequently confined to Members of the Board of Directors with but a few additional interested persons. The Secretary observed that upon discussion of this matter with several A.W.S. prominent members he found opinions divided in regard to the value of publicity and larger attendance.

Mr. Fraser observed that other SOCIETIES have greater attendance at their Annual Business Meetings than A.W.S. does. In order to gain larger attendance at the Business Meeting there is a definite need to have some outstanding event take place at this meeting.

The Board of Directors voted to refer this matter to the A.W.S. Program Committee for consideration and necessary action thereon.

*Scope and Personnel of "Special Committee on Election Procedure"*

At a meeting of the Executive Committee of the Board of Directors on Nov. 3, 1949, the Committee voted favorably on the appointment of a special committee of three to be known as the "Special Committee on Election Procedure." The President directed the Secretary to draft text on the scope of activity for this Committee. The Secretary accordingly did so and submitted to the Board of Directors suggested text on scope of activity for this Committee and upon motion, duly seconded, the Board approved of text as submitted by the Secretary, and as listed below:

"A Special Committee on Election Procedure consisting of three members, comprising a Chairman and two members, all appointed by the President. The duties of the Committee shall be the preparation and submission to the Board of Directors of (*a*) recommendations regarding number of candidates for national officership appearing on national nomination and/or election ballots, (*b*) recommendations on membership and experience requirements of candidates for national and section officership, (*c*) recommendations regarding type and volume of bibliography and qualification publicity on each candidate for national officership, time of release and vehicle to be employed for issuance to Membership prior to nomination balloting, (*d*) recommendations regarding qualification requirements—number, status and residence—of members proposing additional names of candidates, other than those selected by nominating committees, for nomination to national or section officership and (*e*) a guide for selection of candidates for national and section officership for availability to national, district and section nominating committees and other authorized groups or individuals."

*Elimination of W.R.C. Supplement from 1950 Year Book*

The Secretary stated that in past years the SOCIETY issued either a combined Year Book and Membership Directory or an individual Year Book and Membership Directory. Due to the financial condition of the SOCIETY, the Board of Directors previously voted to issue a Year Book during the 1949–50 fiscal year but not to issue a Membership Directory.

The SOCIETY'S 1949–50 budget is based on the 1950 Year Book at 1949 year's cost. Evidence of further increasing production and printing costs indicate that we would exceed our budget were we to duplicate our last year's Year Book. Further, the omission of the Membership Directory necessitates including important information provided in last year's Membership Directory in the 1950 Year Book.

The Secretary discussed the possibility of not including the W.R.C. Supplement in the 1950 issue of the Year Book with W. Spraragen, Director of the Welding Research Council. Mr. Spraragen was of the opinion that a satisfactory arrangement could be made with W.R.C. in the order of (1) the W.R.C. Supplement be excluded from the 1950 Year Book and (2) W.R.C. would have their own Annual Report available and copies, if needed, could be secured from them at cost.

# NEWS OF THE INDUSTRY

## Gas Welding Motion Picture

Production will begin immediately on a documentary film for the International Acetylene Assn. This two-reel color motion picture will be produced by Transfilm Incorporated. The film will describe the basic story of the oxyacetylene flame and show the development of welding as an industrial process.

The film is to be completed and ready for release in April and will review the origin of oxygen and acetylene and their combination to produce the hottest flame known. It will show oxyacetylene replaced the old forging process for joining metals.

## Lincoln Electric Announces Factory Parts Exchange Plan

In order to have guaranteed factory built stators, armatures and other parts available all over the country for welder repair service at lowest possible cost, The Lincoln Electric Co., of Cleveland, Ohio, has established a welder parts exchange plan. Old parts may be traded in for factory-wound stators, armatures and certain control parts. Standard prices in effect include trade-in allowance which reduces the cost for these production-line factory parts below the cost of individual local rewinding and repairing.

This service is available through the 146 Lincoln authorized Field Service Shops in principal cities in 44 different states. Factory trained men are available at each of these Shops for the installation of exchange parts at standard prices. In addition to exchange parts Field Service Shops also provide other welder parts, repair service, preventive service and rental service.

A directory of the 146 Field Service Shops and a complete price list for exchange parts with description of the plan is available from The Lincoln Electric Co., Cleveland 1, Ohio.

## The Aluminum Association Elects Officers

At the annual meeting of The Aluminum Association held January 17-19 in New York, R. S. Reynolds, Jr., of the Reynolds Metals Co., Richmond, Va., was elected president for the ensuing year. The following were elected vice-presidents: E. G. Grundstrom, Advance Aluminum Castings Corp., Chicago; M. E. Rosenthal, United Smelting and Aluminum Co., Inc., New Haven, Conn.; and George N. Wright, The John Harsh Bronze and Foundry Co., Cleveland. A. V. Davis, Aluminum Company of America, New York, was re-elected chairman of the board, and Donald M. White was reappointed secretary and treasurer.

Three directors-at-large were elected to serve for three-year terms: A. P. Cochran, Cochran Foil Co., Inc., Louisville, Ky.; D. A. Rhoades, Kaiser Aluminum & Chemical Corp., Oakland, Calif.; and R. J. Roshirt, Bohn Aluminum & Brass Corp., Detroit, Mich.

Member companies of The Aluminum Assn. account for all the primary aluminum production in the United States and about 85% of aluminum semifabricated products.

## Annual Meeting of IAA

The annual convention of the IAA will be held at the Fairmont Hotel, San Francisco, on March 27, 28 and 29. An interesting program has been developed for this occasion. The James Turner Morehead Medal for the year 1949 will be awarded to James I. Banash, Consulting Engineer, Chicago, Ill., for his many years of stimulating inspiration, guidance and encouragement of the acetylene industry toward higher safety achievements. The presentation of the Medal will be made at the opening luncheon of the annual convention to be held at the Fairmont Hotel, San Francisco, on Monday, March 27, 1950.

## New Headquarters

The American Industrial Safety Equipment Co., manufacturers of Eyegard goggles, spectacles, helmets, face shields and other safety equipment, announces that it will move its manufacturing facilities and offices to 3500 Lakeside Ave., Cleveland 14, Ohio, from 847 Lexington Ave., Brooklyn 21, N. Y. By this action the company will take advantage of better and more economical manufacturing facilities and a more central location in which to continue its developments in the field of eye and body protection.

The new location in Cleveland will enable the company to make overnight shipment to practically any point east of the Mississippi River. The company is moving to a building with facilities designed entirely for the manufacturer of protective equipment, with additional space available for expansion. As a subsidiary of the Burdett Oxygen Co., located adjacently, it will have access to the equipment, facilities and technical skill of one of the largest independent manufacturers of industrial gases and welding equipment in the nation.

It is expected that the entire moving operation will be completed by March 1st. The phone number in Cleveland will be EX-1-7594.

## Canadian Branch Taylor Forge

Taylor Forge & Pipe Works, Chicago, has announced the formation of Taylor Forge & Pipe Works of Canada, Ltd. This new subsidiary will be located at Hamilton, Ontario, and will augment the productive capacity of the company which now has plants at Chicago, Illinois, Carnegie, Pennsylvania and Fontana, Calif. The new facilities at Hamilton will permit the company to participate actively in the Canadian market for the products of its manufacture.

Taylor Forge & Pipe Works was organized in 1900 by J. Hall Taylor who is Board Chairman of the company. The company has pioneered in the manufacture of various important engineering products, notably wrought steel fittings for pipe welding, spiral welded pipe and a wide range of heavy forgings for boilers, pressure vessels and so forth.

Operations at Hamilton will start in a new building now being designed to suit exactly the intended manufacturing. It is hoped that the new facility can be staffed with Canadian personnel.

## International Harvester Fellowship

The Welding Research Council has established two fellowships, one known as the Chicago Bridge and Iron Fellowship, and the other the International Harvester Fellowship. Definite rules have been promulgated for the administration of these Fellowships. Total funds for any one Fellowship amount to $3500, including a stipend for the Fellow, tuition, supplies and the like. The International Harvester Fellowship has not yet been placed. Below are given the problems which may be undertaken by the International Harvester Fellowship. Any university, or Fellow, interested should communicate with W. Spraragen, Director, Welding Research Council, 29 W. 39th St., New York 18, N. Y.

*Subjects for Consideration in connection with the Harvester Fellowship sponsored through the Welding Research Council*

1. The Measurement and Evaluation of Extremely Rapid Heating and Cooling Rates and Their Effect on Carbon and Low-Alloy Steels. It is possible to encounter extremely rapid heating and cooling rates in the spot and projection welding processes. Weld periods of 2 to 5 cycles ($^1/_{30}$ to $^1/_{12}$ sec.) are quite common in high speed spot welding operations. A weld period of this general magnitude would give rise to heating and cooling rates which might be as high as 80,000° F.

per second. The initial phase of such a project would probably consist of developing instrumentation for recording such temperature changes. After this instrumentation has been proved satisfactory, actual cooling and heating rates and their effect on the physical properties and/or structure probably should be studied.

2. The Physics of Flash Welding. There is considerable controversy concerning the relative values of the various sources of heat which are available in the flash welding process. Examples of these sources are the resistivity of the material, the electric arc, the oxidation of the material, etc. The initial problem would probably be to determine a means of measuring or isolating the heat produced by the several sources. In addition to the above, it is expected that this work would involve a complete study of the physics of flashing.

Investigation of Item No. 1 would be preferred by the International Harvester Co. at the present time.

### Vosco Appointment

The Vosco Electric Sales Co., of 11 Court St., Newtonville 60, Mass., formed by Jim Vosburgh and Paul V. Galambos, has been appointed Eastern representative for the Mir-O-Col Alloy Co., manufacturers of the well-known Mir-O-Col hard-facing electrodes and rods, covering the states of Maryland, Delaware, Pennsylvania, New Jersey, New York, and New England. Both gentlemen were formerly connected with the Glenn-Roberts Co. and have had years of experience in the welding supply business.

### Tungsten Carbide Hard Facing Saves Wear on Trowler Shoes

Trowler shoes, the steel blades used in "troweling" or forming the inside surface of concrete pipe, are among the shortest lived parts in any industrial use. Rotating constantly and exerting enough pressure to squeeze moisture out of "dry-mix" concrete, they are the victims of extreme abrasion. In the experience of Fowler & Meyers, concrete pipe makers of Somis, Calif., trowler shoes had to be replaced every three hours.

As a test for resistance to wear, two shoes were hard faced with Amsco Tube Tungsite 30-40, a tungsten carbide type welding rod, while other shoes on the machine were left unfaced. The result of the test is shown in the above photograph. The two shoes at the left were coated while the one on the right was not. The uncoated shoe is so badly worn that it must be discarded, while the other two may be rebuilt when worn, to original dimensions and returned to service. Shoes hard faced

*Trowler shoes. Two shoes at left are hardfaced. Shoe on right is unfaced.*

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with tungsten carbide, as these have been, will last a full eight-hour shift, as compared with the unfaced shoes mentioned above which had to be replaced every three hours. They can be repeatedly rebuilt and kept in service. The saving in replacement parts is considerably greater than the cost of hard facing; and, in addition, there is saving in production time due to less frequent replacement of shoes.

For information write: American Manganese Steel Division, American Brake Shoe Co., 389 E. 14th St., Chicago Heights, Ill.

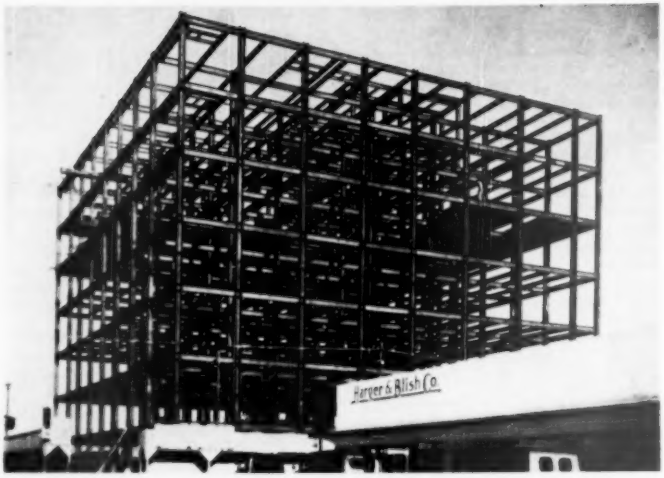
### Bell Telephone Building

The Southwestern Bell Telephone Co. are owners of the latest welded-steel building frame to be completed in the City of Houston, Tex. This structure involves 1755 tons of steel in seven floors to be completed under the present contract, but the foundation design is reported to be adequate for seven or eight additional floors at some future date. Each floor contains 17,000 sq. ft. of space with building dimensions approximating 125 x 140 ft.

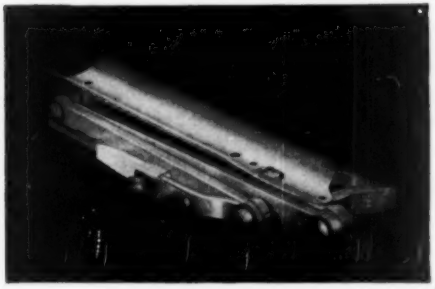
Structural design details for this building were worked out by R. J. Cummins, Engineer, Houston, in cooperation with telephone company engineers and architects, and the steel fabrication and erection contract was awarded to Mosher Steel Co., Houston.

All beam to column connections were made by butt welding beam flanges to columns, and plates were welded between column flanges to develop continuity. Beam web connection plates were put on columns in the shop to afford a means of convenient erection, and a vertical fillet weld was made to complete this connection in the field.

Welding operations in both shop and field work were done in accordance with the American Welding Society Code for Arc Welding in Building Construction. Southwestern Laboratories, Houston, supervised details of shop fabrication, erection and welding in accordance with requirements of the A.W.S. Code.







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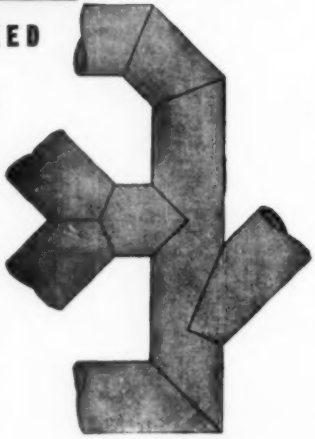



### Purdue Welding Conference
### The Twenty-first Annual Purdue Welding Conference May 3–4, 1950

### New Welding Processes to be Discussed and Demonstrated

Mechanical rectifier arc welders, submerged arc welding, stud welding, gas welding and high-frequency induction welding are among the numerous new welding processes and machines to be discussed at the Second A.I.E.E. Conference on Electric Welding, April 5th, 6th and 7th in Detroit, Mich.

New data on voltage dip effects and voltage drop interference between welders will aid in future designs of power supply systems for resistance machines. A technical session on power supply will also consider welder feeder systems and the use of series capacitors at main transformer primaries.

Sessions on instrumentation, arc- and resistance-welding equipment, and basic arc research are further highlights of the three-day program.

Two evenings will be devoted to practical demonstration of welding machines and new techniques. Advance registration cards and programs are available from E. D. Kane, Registration Chairman, Detroit Edison Co., 2000 Second Ave., Detroit 26, Mich. This Second Welding Conference is sponsored by the American Institute of Electrical Engineers in cooperation with the AMERICAN WELDING SOCIETY and the Industrial Electrical Engineers' Society of Detroit.

# PERSONNEL

## J. Lyell Wilson Becomes Consultant

J. Lyell Wilson has announced his retirement from the American Bureau of Shipping and the establishment of a consulting practice in naval architecture, marine and welding engineering. Lyell offers to these industries an unusual background which can hardly be surpassed.

Mr. Wilson graduated from Webb Institute of Naval Architecture in 1914. He is a trustee of that institution. There followed several years of practical experience as a ship fitter, design draftsman and chief draftsman for two shipbuilding companies and an engine company. Mr. Wilson joined the American Bureau of Shipping and has had thirty-three years of continuous service with that organization as surveyor, assistant chief surveyor and as research director. Mr. Wilson is a licensed engineer of the State of New York. During the war he was assigned as Special Assistant to the Chief of the Bureau of Ships, U. S. Navy Department. For the last seven years he has been a member of the Sub-Board to Investigate the Design and Construction of Welded Steel Merchant Vessels, appointed by the Secretary of the Navy and subsequently the Ship Structure Subcommittee.

Mr. Wilson is a member of a number of professional societies including the Society of Naval Architects and Marine Engineers and the AMERICAN WELDING SOCIETY. He is a member of a number of technical and research committees of both societies and is currently chairman of the Committee on Welding in Marine Construction of the AMERICAN WELDING SOCIETY. He also serves on a number of research committees of the Welding Research Council, including Structural Research and Pressure Vessels. He is a member of the Joint Committee on Gas Hazards of the American Bureau of Shipping and the National Fire Protection Association.

Mr. Wilson has written a number of papers among which are the following:

Control Committee on "The Principles of Naval Architecture," S.N.A.M.E.
Chapter on "Reciprocating Steam Engines" in *Marine Engineering*, S.N.-A.M.E.
Chapter on "Classification Society Rules and Interconnection of Government in the Shipping Industry" in *The Shipbuilding Business in the United States of America*, S.N.A.M.E.
"The S.S. Leviathan; Damage, Repair and Strength Analysis," S.N.A.M.E.
"The Control and Inspection of Quality Welding," A.W.S.
"Some Notes on the Investigation of Welded Ship Construction," A.W.S.
"Preliminary Results of Welding-Peening Investigation," A.W.S.

Elsewhere in this issue there is published a report of Mr. Wilson's work on the welding-peening investigation.

His address is 145 Clifton St., Westfield, N. J.

## Walter Samans Opens Consulting Office

Walter Samans for many years connected with the Sun Oil Co., has launched a consulting engineering practice on unfired pressure vessels and tanks. Mr. Samans will specialize in investigations of failures in service; check on designs of new and existing vessels, supports and foundations for such vessels. Also recommendations for repairs or reconstruction.

Mr. Samans is a Licensed Professional Engineer of Pennsylvania; a member of the A.S.C.E, A.S.M.E. and A.W.S. He is a past chairman of the Unfired Pressure Vessels Committee of the Boiler Code Committee. Past chairman of the W.R.C. Pressure Vessel Research Committee and of the Joint A.P.I.-A.S.M.E. Committee on Unfired Pressure Vessels. He is also past vice chairman of the A.P.I. Committee on Steel Storage Tanks.

His address is 1616 Walnut St., Philadelphia 3, Pa.

## E. L. Mathy Appointed Consultant

Hugh Brown, President, and George Hammon, Vice-President and General Manager, of the West Coast's oldest company engaged in the development of welding and of welding equipment, the National Welding Equipment Co., of San Francisco, announce the appointment of E. L. Mathy as Sales and Advertising Counselor. Mr. Mathy, well known in industrial circles from coast to coast, personally developed and guided the sales promotional and advertising operations of the Victor Equipment Co. whom he served in the capacity of First Vice-President and Director for over twenty years.

Mathy also worked for the Air Reduction Sales Co. for approximately five years and prior to that time had his own company which developed and marketed gas welding and flame-cutting apparatus. He has been closely connected with industrial marketing operations for over thirty years and served as President of the San Francisco Sales Managers' Association and as President of the Northern California Industrial Advertisers' Association. He was Chairman of the AMERICAN WELDING SOCIETY, San Francisco Section, and has been a National Director both of that SOCIETY and of the International Acetylene Association. Mr. Mathy has been a prodigious contributor to technical and semitechnical publications and has been the author of numerous manuals and engineering treatises.

Mr. Mathy, who lives in Orinda, Calif., served his own community as its first President of the School Board. During the late World War his neighbors appointed him as Coordinator of Civilian Defense.

Mr. Mathy, an acknowledged leader in industrial sales promotion and advertising activities, is an experienced engineer who thus brings to his marketing job the fuller understanding of a man who has devoted a lifetime to mechanical and technical problems. He plans to confine his consulting services to a very limited number of clients because he believes that he may thus serve by far more effectively than were he to divide his time and his efforts too much.

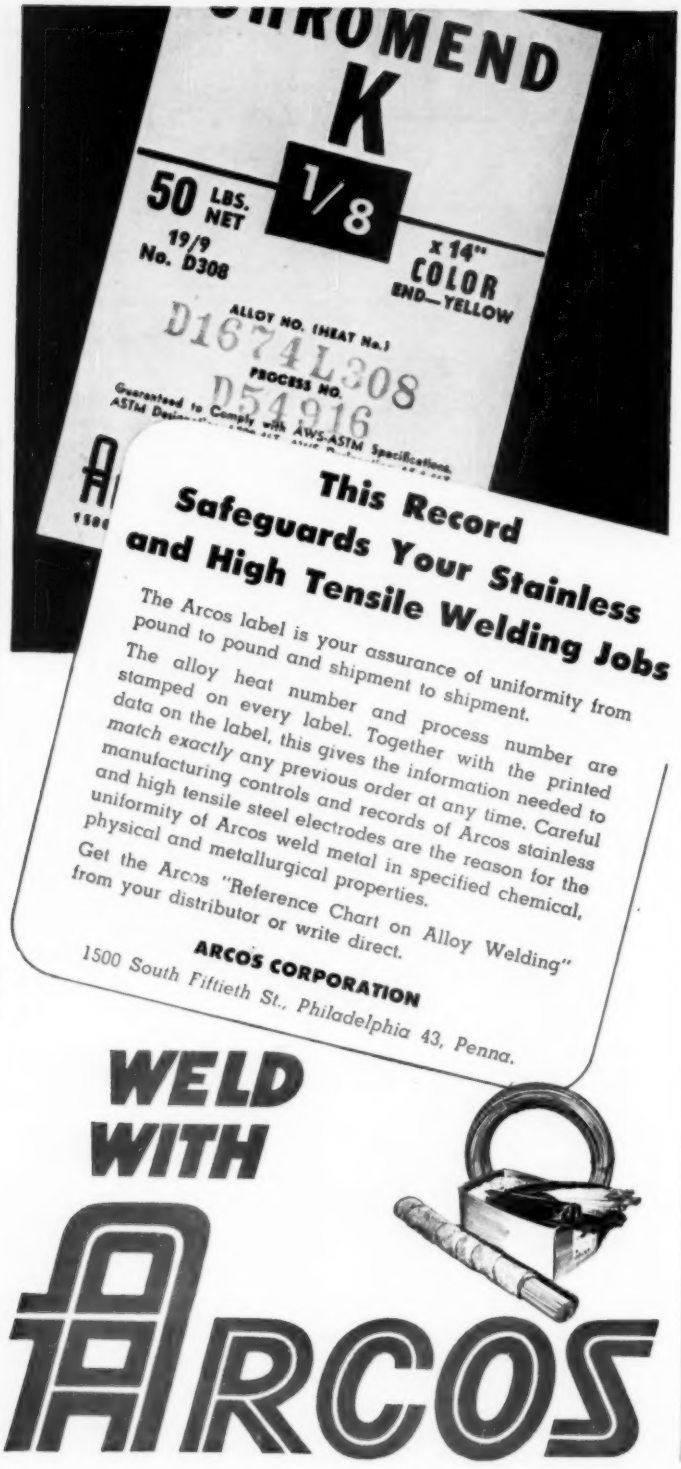
## Medoff Joins Welding Engineer

Jack I. Medoff, Assistant Technical Secretary of the AMERICAN WELDING SOCIETY has left his position with the SOCIETY to become Eastern Editor of *The Welding Engineer* effective Feb. 1, 1950. Jack joined the A.W.S. staff on Aug. 1, 1948, as Assistant Technical Secretary and Assistant Editor of *The Welding Handbook*.

While with the SOCIETY, Mr. Medoff assisted in the preparation and revision of codes and specifications of the SOCIETY and the dissemination of technical information. Mr. Medoff acted as Assistant Editor of the Second Edition of *Welding Metallurgy* and the Third Edition of *The Welding Handbook* just off press.

In addition to his direct experience in editorial and code work with the SOCIETY, Mr. Medoff has an interesting background which should stand him in good stead in becoming Eastern Editor of the contemporary magazine, *The Welding Engineer*.

Before joining the SOCIETY Mr. Medoff conducted a general metallurgical consulting and laboratory service. He served as a naval officer from 1943 to 1946 reaching the rank of Lieutenant Commander at the time of his discharge from the Navy. Prior to joining the Navy, Mr. Medoff was Metallurgist and Chief Radiographer of the Worthington Pump and Machinery Corp. at their Harrison and Holyoke plants. He was transferred from the Harrison Works of the Corporation to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organize and supervise the X-Ray Department of the welding of the new Ordnance Division, manufacturing 90-mm. AA gun carriage for the U. S. Army; to qualify the radiographic procedures and supervise all radiographic inspection of welding to government standards established at the Watertown Arsenal; to conduct radiographic and physical testing for qualification of welders; and to conduct and supervise all metallurgical testing as required in the division.

Mr. Medoff was graduated from Cooper Union Institute of Technology in 1936 with the degree of B.S. in Chemical Engineering. He has advanced studies at Brooklyn Polytechnic Institute, Princeton University, Harvard and Stevens Institute of Technology.

Mr. Medoff is a member of the American Society for Metals, AMERICAN WELDING SOCIETY, Society for Nondestructive Testing and the Metal Science Club of New York.

### Southard Appointed to Committee N.A.C.A.

Dr. John C. Southard, member A.W.S., who is Director of Research for Solar Aircraft Co., San Diego, Calif., has been appointed a member of the subcommittee on Aircraft Structural Materials, a technical subcommittee of the National Advisory Committee for Aeronautics. Dr. Southard holds a Ph.D. in Physical Chemistry from Johns-Hopkins University. Before joining Solar in 1946 as manager of the Factory Laboratory, he served with the U. S. Dept. of Agriculture, with the U. S. Bureau of Mines and as Chief of Process Metallurgy Research with the Titanium Alloy Mfg. Co.

### Jarboe Takes on G-E Line

The Drill Master Supply Co., 1305 First Ave., Evansville, Ind., has recently been appointed a General Electric Welding Distributor for southwestern Indiana Territory.

T. B. Jarboe, Manager of Welding of the Drill Master Supply Co., stated that a complete line of G-E welding equipment electrodes and accessories including a. c., inert-arc, atomic hydrogen and d.-c. welders would be carried by his department. Mr. Jarboe is a member of the AMERICAN WELDING SOCIETY.

## OBITUARY

### Robert Jaskulek

The Burdett Oxygen Co. announces with deep regret the passing of Robert Jaskulek on Jan. 6, 1950. Mr. Jaskulek, in his contacts with welding engineers, had a large number of friends throughout the Ohio territory. He was a member of the Board of Directors and senior salesman for over 27 years for the Burdett Oxygen Co., 3300 Lakeside Ave., Cleveland 14, Ohio. Mr. Jaskulek was a member of THE AMERICAN WELDING SOCIETY.

# EVERDUR

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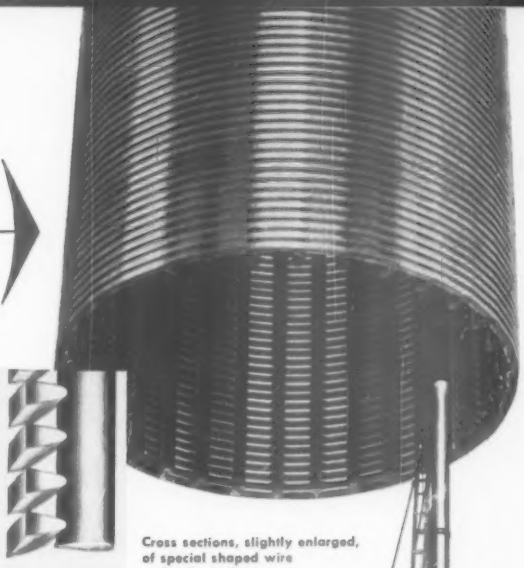
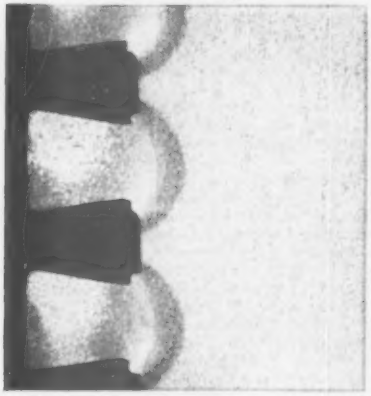
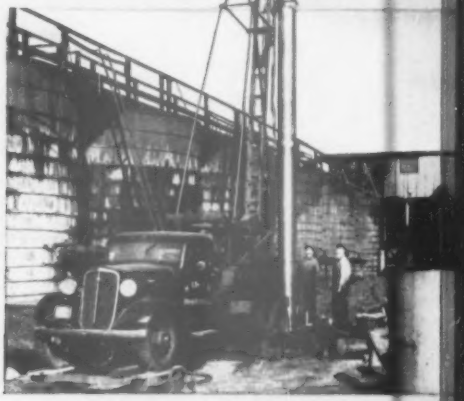


Cross sections, slightly enlarged, of special shaped wire and rod members.

Well screen being fabricated by unique method of resistance welding.



Micrograph of lengthwise section showing excellent fusion of Everdur resistance welds.



Johnson Well Screen, 16" O. D., 35' long, being lowered into well casing.

Longitudinal rods and outer wire in this Edward E. Johnson, Inc., well screen are both Everdur® 1010 and of special cross section. Fabrication of the screen is quickly and economically accomplished by rotating the rod assembly, thus winding on the wire and automatically welding wire to rod by electrical contact.

The circuit is arranged so that the rod assembly becomes one electrode, the other electrode being a copper roll which rides on the wire. As the latter touches each rod a surge of current welds the wire to the rod. Welding is at the rate of from 900 to 1700 welds per minute, depending on the size of the wire and rod. Only two or three cycles of current are required for each weld.

Everdur Alloys are non-magnetic and highly resistant to fatigue. Alloys are available which can be machined, hot-forged, drawn, stamped, spun, cast, electric-welded or oxy-acetylene-welded by all modern methods and equipment. For detailed information regarding compositions, properties, applications and advantages, ask for Publication E-5. Our Technical Department is at your service. Write The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 49108

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# NEW LITERATURE

### Portable Gas Drive Arc Welders

Hobart Brothers Co.'s 4-page illustrated folder shows and describes 15 features of gasoline engine-driven arc welders. Also shows specifications of 10 different models of gasoline engine-driven arc welders and combination models of arc welders and power units.

### Arc Welding Machine Catalog

A new arc welding machine catalog, the first to include all the machines in the Airco line, has been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc.

The 36-page, illustrated catalog, the fourth of a projected series of ten, is divided in two parts, the first dealing with a.-c. arc welders, the second with d.-c. machines.

The descriptive text gives distinctive features, operating data, specifications and other pertinent information about each machine.

For a free copy of this new catalog, write the Airco sales office nearest you or Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

### Automatic Arc Welding

The Reid-Avery Co., Inc., Dundalk, Baltimore 22, Md., has issued a four-page folder describing various types of coil wires available for submerged arc welding. These include pure iron, mild steel, high tensile steel, high manganese and high manganese molybdenum.

Another four-page folder describes automatic welding electrodes for the open arc. Either of these is available on request.

An attractive eight-page brochure gives technical information on shielded-arc automatic welding electrodes and the Reid-Avery line in this field.

### Hard Facing

Just published a five page booklet, "Hard Facing Farm Equipment with Colmonoy" by Wall Colmonoy Corporation, 19345 John R. Street, Detroit 3, Michigan.

The booklet gives complete details on hard facing six (6) tried and proved farm applications. Each application is thoroughly outlined as to procedure for hard facing plus sketches indicating exact area to be hard faced for maximum wear life.

### Spot Welder

New catalog sheet on the Birdsell 4, 6 kva. Model No. 130 T spot welder with electronic timer. Outstanding features such as watercooled electrodes and secondary coil, capacity of two pieces of 16 gage cold-rolled steel, operation through a simple 60 amp. switch, single phase, 220 v., 18-in. arms and economies in operation with electronic timer are listed. Back page contains operating instructions and diagrams. Mailed free to those interested in spot-welding operations. Write to Birdsell Products, P. O. Box 733, Los Altos, Calif.

### Welding Fittings

Catalog No. 211 provides complete dimensional data, weights and prices on all Tube-Turn welding fittings and flanges. The Engineering Section contains practical, illustrated information covering Tube-Turn welding fittings and flanges under varying conditions of temperature, pressure, location and materials processed. It discusses the use of Tube-Turn fittings and flanges in many different types of piping systems, demonstrating their flexibility.

A section is also devoted to Tube-Turn welding fittings and flanges in special metals and alloys, and includes helpful information on the various services for which each type is best suited. The Technical Section reflecting the results of extensive research, calculations, and experiment, contains valuable data on Properties of Pipe; Rating of Pipe, Fittings, and Flanges; Line Expansion and Flexibility; Support and Anchorage of Piping; and Flow of Fluids.

Every copy of No. 211 will be registered in the name of its owner, so that he can be regularly supplied with supplemental data and literature.

Because No. 211 has been costly to produce, its distribution will be restricted to major users, designers and erectors of industrial piping.

### Automatic Welding Positioner

The Aronson Machine Co., Arcade, N. Y., has issued an attractive two-page circular describing their Model 14AW300 positioner of 300 lb. capacity. This positioner is a "Universal" tool ideally suited to positioning work in any attitude, especially adapted to automatic welding, providing infinitely variable work rotation speeds for circular welding, with a minimum of tooling-up required.

### Gas Welding Rods

The Reid-Avery Co., Inc., has issued an attractive four-page circular describing their oxyacetylene welding rods and wire for gas-shielded arc welding. Copy is available on request to Reid-Avery Co., Inc., Dundalk, Baltimore, 22, Md.

### Cutting Maintenance Costs

Cutting Maintenance Costs with Aluminum-Bronze Electrodes," was the subject of a paper presented at the 13th annual meeting of the AMERICAN WELDING SOCIETY, by Joseph A. Cunningham, President of the J. A. Cunningham Equipment Co., Philadelphia, Pa.

Reprints of this paper can be obtained for the asking from Ampco Metal, Inc., Milwaukee 15, Wis.

### Spot Welding Aluminum

The Metal Industries Dept. of The Diversey Corp., Chicago, now has available three new pieces of informative literature concerning the characteristics, applications and production records of two of their products and one of their processes.

Diversey No. 12, a reverse current electrocleaner for steel, copper and copper alloys, and Diversey No. 36, an alkaline, nonetching aluminum cleaner, are each thoroughly discussed in two of the file folder-type pieces of literature.

The third folder, a 12-page manual, is a technical presentation of The Diversey Pretreatment of Aluminum for Spot Welding. The process is described in detail and the reasons for and advantages of the outstanding characteristics of the process are discussed. Many pictures, charts and graphs add to the extraordinary completeness of this literature. Very interesting case-histories support the claims for this process.

Copies of this literature may be obtained by writing to The Diversey Corp. on your company stationery.

### Hard Surfacing Materials

Rankin Manufacturing Co., producers of hard surfacing welding materials, announces a new catalog. Hard surfacing rods and electrodes for gas and arc welding are illustrated, along with qualities, types and Rockwell hardness. Most interesting is the listing of nearly 200 recommended applications catalogued by industries, and the specific type of welding material that is to be employed.

Copies of this new catalog are available from Rankin Manufacturing Co., 3072 W. Pico Blvd., Los Angeles 6, Calif.

### Resistance Welding Control Equipment

New Westinghouse electronic resistance welding control equipment, both synchronous and nonsynchronous, is described in detail in booklet B-4309.

Basic equipment in the control circuit includes a sequence-weld-timer panel and a means to fire the ignitron tubes in the power circuit. Auxiliary control panels can be readily added to meet specific job requirements. This booklet lists and discusses the functions of both basic and auxiliary control panels.

For a copy of this booklet (B-4309) write Westinghouse Electric Corp., P. O. Box 2099, Pittsburgh 30, Pa.

### New Rings Folder

Dresser Manufacturing Division, Bradford, Pa., has issued a new two-color illustrated folder which explains the manufacturing processes involved in the fabrication of stainless and other steel rings, motor-frame assemblies, and a wide variety of other ring shapes and weldments. Featured is the story of a four-ring motor generator frame. Copies will be furnished on request.

### Electrode Catalog

A 16-page, $8^1/_2$ x 11 electrode catalog is announced by Hobart Brothers Co., Troy, Ohio, containing a description, data on the application, welding procedure, mechanical properties and specifications of electrodes in the Hobart line.

### Literature Item

A new specification sheet has been released which gives complete data on the heavy duty toggle clamps manufactured by General Welding Corporation of Cleveland, Ohio. Included are sketches giving all dimensions. Pressures are provided and outstanding features are listed. Price list is attached.

### Aluminum Bulletin

This bulletin is published quarterly for The Aluminum Association by Dudley, Anderson & Yutzy, 551 Fifth Ave., New York 17, N. Y. The winter issue contains interesting references to new welding methods.

### Welding and Cutting Catalog

The Dockson Corp., 3839 Walnash, Detroit 8, Mich., has just issued their complete catalog No. W-50, on welding and cutting equipment and supplies. This catalog, copiously illustrated, consists of 48 pages and covers. It represents a complete line of equipment and accessories.

### Welding Wall Chart

A mine of valuable welding information is to be found on a new two-color giant wall chart which may be had free by writing on your letterhead to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

This illustrated chart, measuring nearly 2 by 3 ft., lists over one hundred EutecRods and EutecTrodes with their standard sizes, giving for each rod such technical data as: type of joint for which suitable, metal on which used, bonding temperature, tensile strength, Brinell hardness, degree of color match, electrical conductivity, resistance to corrosion, flame adjustment, etc.

There is also a section on the 33 most important Eutectic Alloys, with a brief discussion of their properties. A brand new useful feature is a check list of close to 300 production and maintenance applications, with the rod or rods recommended for each case—a list which every welder will value.

### Tuffalloy Catalog

A new simplified resistance welding alloy catalog of standard tips, special tips, holders, bar stock, forgings, castings and prices. R.W.M.A. specifications and recommended electrode materials for resistance welding are included in easy to read tables, along with other helpful suggestions. Free. Welding Sales & Engr. Co., 8750 Grinnell Ave., Detroit 13, Mich.

### Welding and Cutting Fumes and Health and the Welder

A 13-page reprint of three outstanding articles published by *The Welding Engineer* to answer authoritatively common questions on health hazards in welding; illustrated; complete bibliography on subject; reprints available from The Lincoln Electric Co., Cleveland 1, Ohio; price 25¢.

### Warco Inclinable Presses

A new illustrated bulletin by The Federal Machine and Welder Co., Warren, Ohio, presents a line of high-speed precision production inclinable welded presses with special emphasis on the needs of the press user. Featuring the WARCO Pneumatic Clutch and Brake, these open-back inclinable presses range in sizes from capacities of 40 to 200 tons, with stroke lengths made to suit customer's requirements.

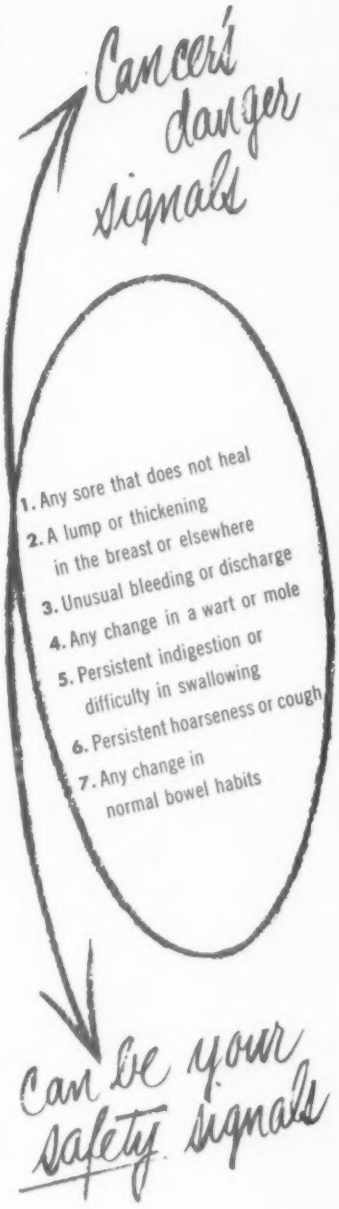
Specifications, sectional drawings with identifying parts lists, and other useful data are contained in this latest of WARCO publications.

### Steel Casting Reference Charts

Two newly revised steel casting reference charts covering 33 selected grades of carbon and low alloy, stainless, corrosion- and heat-resistant alloys have been compiled by Lebanon Steel Foundry, Lebanon, Pa.

Incorporated in the charts is detailed reference material on specification designations, analyses, physical properties, heat treatments and related data on 18 high alloys and 15 low alloys and carbon steels developed to fulfill a wide range of exacting engineering and design requirements for varied industrial applications.

Carbon and low-alloy steel castings covered in one chart include recommended Circle-L grades, which provides the engineer with fifteen grades suitable for a variety of services where welding, high-structural strength, and creep resistance are paramount. Several grades of high-strength castings with a broad range of



Cancer's danger signals
1. Any sore that does not heal
2. A lump or thickening in the breast or elsewhere
3. Unusual bleeding or discharge
4. Any change in a wart or mole
5. Persistent indigestion or difficulty in swallowing
6. Persistent hoarseness or cough
7. Any change in normal bowel habits
Can be your safety signals

Cancer is curable if discovered early and treated properly

If any of these symptoms appear, see your doctor at once.

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AMERICAN CANCER SOCIETY, INC.

physical properties are offered and derived by controlled heat treatment methods. A series of low-alloy steels are also included for high-temperature power and oil refinery service, which allows the engineer a selection of alloys most ideally suited to the pressure and temperature conditions to be employed. These grades of carbon and low-alloy castings are suited for many industrial applications, particularly pressure fittings, such as valves, pumps and parts and miscellaneous machinery castings such as cams, cranks, pneumatic drill and power driveparts requiring special properties which may include fatigue, wear and impact resistance.

The second chart covering stainless, corrosion- and heat-resistant alloy castings is devoted to 18 selected Circle-L grades. This group of alloys provides the engineer with materials of construction, resistant to varying types of corrosion as encountered in the chemical, oil and refining, paper and pulp, textile, food processing and other industries.

Some of these alloys are ideally suited to extreme ranges of temperature from the most frigid applications to very high temperature services. Typical castings being produced from these various grades include valves, fittings and pump parts for corrosive services, as well as intricate castings for the jet airplane, gas turbine components, and other heat-resistant applications where strength at elevated temperatures and stability are required.

Along with Lebanon Circle-L grade designations, the charts list comparable designations of Alloy Casting Institute (A.C.I.), American Iron and Steel Institute (A.I.S.I.), American Society for Testing Materials (A.S.T.M.), Hydraulic Institute, Society of Automotive Engineers (S.A.E.) and U. S. Navy Steels.

Copies are available from Warden F. Wilson, General Sales Manager, Lebanon Steel Foundry, Lebanon, Pa.

## Welding Dictionary

*Welding Dictionary:* French, German, Spanish, English. Compiled and Edited by R. N. Thompson, Editor of *Welding* and G. Haim. Published on January 23, 1950 at 21s. (postage 6d) by The Louis Cassier Co., Ltd., and distributed by Iliffe & Sons Ltd., size Covo (7½ x 5 in.), 234 pages. Bound in Imitation Leather with jacket.

Like all new techniques, welding has given rise to a considerable number of new words and phrases which have specialized meanings. This leads to difficulties in the reading of foreign literature because these new welding words and expressions are not to be found in the dictionaries so far available.

The purpose of this dictionary is, therefore, to enable the welding engineer and research worker with an average knowledge of another language beside his own to be able to understand easily the technical publications of a different country.

In addition to terms specifically related to welding, many other expressions pertaining to electrical and mechanical engineering and to metallurgy are included, as the ready translation of such terms are essential for the appreciation of any welding literature.

The dictionary has been divided into four parts—French, German, Spanish and English—the English part being treated as a key glossary with equivalents in the other three languages. Copies of this book may be purchased in the United States at the British Book Centre, 122 East 55th Street, New York, N. Y.

## Percussion-Welding Developments

Considerable interest is being shown in the improved flash welding methods revealed by Reynolds Metals Co., Louisville, Ky., in the current issue of the Company's technical publication, "Technical Advisor," No. 12.

In that issue, Charles Bruno, Reynolds welding specialist, discloses improved percussion welding methods which now make it possible to flash weld aluminum tubing directly to copper, stainless steel, Monel or other alloys without regard to the dissimilar metals in the joint. This is made possible by reducing the fusion zone in the weld to less than one thousandth of an inch in width. Such a fusion zone is so small that practically no intermixing of elements occurs.

Neither is there any change in grain structure alongside the weld. This is an important feature because it opens up a whole new field for the application of aluminum tubing and extruded shapes which can now be welded in the heat-treated condition with hardly any decrease in strength through the weld.

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Cut down your resistance welding or brazing costs! Speed up your work! On a typical high temperature job where ordinary carbons were changed hourly, Stackpole Carbons processed with our new "F" treatment lasted all day! Three to four times longer life on the average elevated temperature job is an extremely conservative estimate of the saving involved. And they require dressing only about one-third as often!

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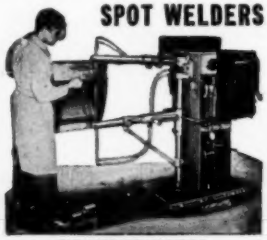

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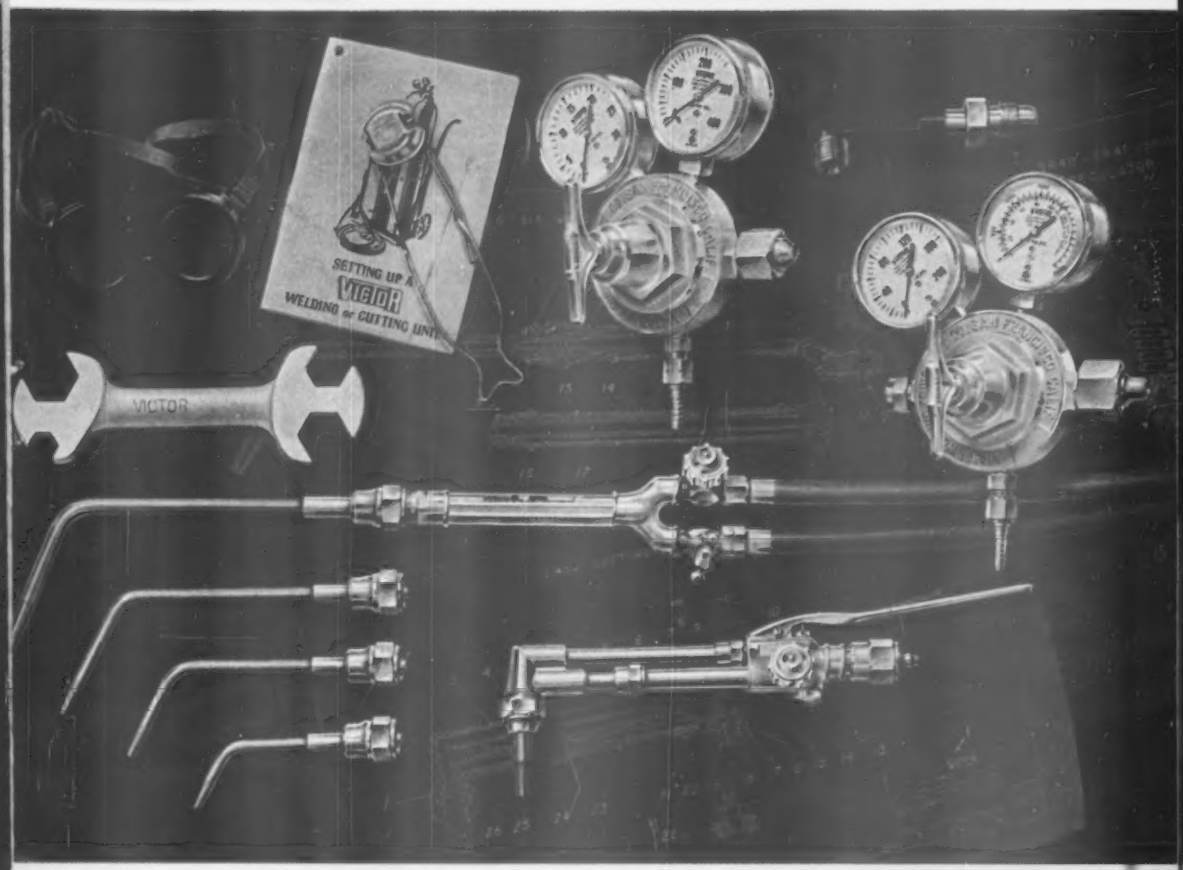


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Thus high-strength aluminum alloys (stronger than structural steel) can now be heat treated at the mill and weld fabricated by the user without materially reducing the mechanical properties of the high-strength, heat-treated aluminum. This eliminates the former problem of how to heat treat large or complicated welded assemblies.

This development also has great significance in refrigeration work where it is now possible to butt weld tubing without any metal being upset on the interior of the tube. The ability to make quickly gas-tight joints in tubing without any interior flash opens up a whole new field for application of aluminum tubing in refrigeration work. Already at least one large producer of refrigeration equipment is exploring the possibilities presented by this new development.

Reynolds Metals "Technical Advisor" is sent free upon request to anyone who wishes data on latest methods for fabricating and processing aluminum and its alloys. Address requests to Reynolds Metals Co., 2500 S. Third St., Louisville 1, Ky.

## Symposium on Metallography in Color

This outstanding symposium, presented at a recent A.S.T.M. Annual Meeting, has just become available in printed form (Special Technical Publication No. 86). Sponsored by A.S.T.M. Committee E-4 on Metallography, it presents the latest thoughts and practices in this field in which there is a steadily growing interest. Leading authorities prepared the papers, with discussions of the various techniques used to record the characteristic colors seen visually. Described are some of the fundamental requirements of the microscope so that good color work would result, others touch on the techniques of photogr.phy and they contain valuable information which can be used to advantage in everyday work in the field of metallography.

The book is illustrated with ten insert plates (four-color process photomicrographs) and includes an Introduction by L. V. Foster, and six papers covering the following subjects: Metallography in Color, R. P. Loveland; Microscope Optics for Color Metallography, James R. Benford; Quality and Quantity of Illumination in Color Metallography, R. P. Loveland; Color Metallography Simplified, Mason Clogg, Jr.; Some Applications of Color Metallography, W. D. Forging; and The Application of Color Photography to the Study of Nonmetallic Inclusions, A. M. Hall and E. E. Fletcher.

Copies of this 80-page symposium, including color plates, can be obtained from American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $4.50 each, heavy paper cover, or $5.15 each, cloth cover.

## How to Design with Aluminum Extrusions

The basic engineering principles that will enable the designer to use extruded aluminum shapes most effectively are well explained and illustrated with many examples in the new 138-page book, *Designing with Aluminum Extrusions*, just published by Reynolds Metals Co., 2500 S. Third St., Louisville 1, Ky. The books are available without charge to engineers, architects, designers and others requesting them on company letterhead.

The section on manufacturing possibilities explains the broad range of shapes that can be produced by the extrusion process. Another chapter correlates shape design with manufacturing limits and shows how many of these limitations can be offset by proper design.

Since certain extruded shapes are used as structural or load-carrying members, a chapter is devoted to the principles of structural design.

The characteristics of aluminum itself, the selection of the correct alloy and temper, fabricating properties, finishes and cost factors are also covered as separate chapters in the book.

In addition, the tabular section presents 16 tables (22 pp.) of data on chemical, mechanical and physical properties of aluminum; extrusion process data such as minimum thicknesses, maximum lengths, tolerances, difficulty factors and the like. Condensations of finishes and joining methods form two tables of special value.

This 138-page, 6 x 9-in. pocket-size book is complete with more than 390 illustrations, a table of contents, index of tabular material, index of illustrations and an itemized cross index covering text, illustrations and tables. It is wirebound to lie flat when open. The book was written by H. V. Menking, Assistant Director, Technical Service Dept., Reynolds Metals Co., Louisville, Ky.

## Electric Arc-Welding Procedure and Practice

In its new 544-page book, *Electric Arc Welding*, The Hobart Trade School, Troy, Ohio, has made available a comprehensive and practical textbook on the procedure and practice of arc welding, which is of outstanding value not only for the student, but also for the practicing welding engineer, welding operator and designer, as well as for executives and supervisors interested in welding procedure and practice.

Clearly written, the 28 chapters are divided in five parts: (1) General Information; (2) Operator Training Course; (3) Carbon Arc Welding and Cutting; (4) Other Welding Processes; (5) Welding Terms and Their Definitions.

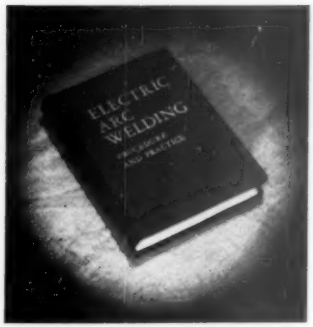
Part 1 discusses the development of electric arc welding, describes applications, available metals and alloys, joints and welds, electrodes, equipment and other basic procedures.

Part 2 constitutes a complete self-study course, incorporating review summaries, practical exercises and "quiz" questions.

Part 3 describes in detail the principles and practical operations of carbon arc welding.

Part 4 covers other welding processes such as inert-gas-shielded arc welding, submerged arc welding and electric stud welding.

Part 5 reproduces the welding terms and




their definitions of the AMERICAN WELDING SOCIETY.

The textbook is illustrated with over 600 photographs of operations, diagrams and charts. The cost of this publication is $3.00.

## The Metal Show

"Surveying the Field" is the third report in a continuing attendance analysis for the Metal Shows. It contains all the information about the 31st National Metal Congress and Exposition held in Cleveland, Oct. 17–21, 1949.

A complete analysis of those attending the Show is included—35,588 visitors—information secured from the registration cards and tabulated and verified by International Business Machines, Inc. Total number of visitors classified by business and industry, by title and occupation and by geographical location.

Floor plans for the 1950 Metals Show to be held at the International Amphitheatre in Chicago are being sent to exhititors at the present time. Space assignments will be made on or about March 20th. Inquiries should be addressed to W. H. Eisenman, Director, National Metal Exposition, 7301 Euclid Ave., Cleveland 3, Ohio.

## Case Histories on Welding Stainless Steel

A brochure on some interesting aspects of arc welding stainless steel with new Eutectic Staintrodes, illustrated with verified case histories, is available from Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Featured in the case histories is Eutectic's full line of Staintrodes, the most advanced type of stainless steel electrode for low-heat welding. Because stainless is used on so many jobs of a critical nature, the Staintrode properties of ultra-high corrosion resistance, and the ability to produce sound welds without undercutting, weakening or warping the base metal, are especially helpful.

Most informative of the case histories described in this folder is that of the construction of a piping system for an Atomic Energy Power Plant. The complications involved in the exacting fabrication of this apparatus appeared all but insurmountable.

For your free copy of this booklet, request Form EU-19 from Eutectic, at the address given above.

## Stop Corrosion with Metallizing

The January issue of the *Metco News* reports that sprayed metal coatings are giving positive protection against corrosion for many years under very severe conditions. For instance, the Bureau of Water, Erie, Pa., started to use metallizing in 1930, when they sprayed zinc on all bolts and nuts on a 72-in. diameter, 8800-ft. intake. In 1932 a 110,000-gal. wash water tank, which had been in service only 18 months showed heavy corrosion on its interior. It was metallized with 0.006-in. pure zinc, which stopped the corrosion completely. Six years later there was no sign of rusting, even though the tank interior is exposed intermittently to water and air. Since then they have used metallizing to stop corrosion on steel filter beds, boiler plant feed water treatment tanks, steel ladders, sluice gates, brace rods and many other parts, normally subject to corrosion.

In 1933, another user metallized the interior of water storage tank with zinc. In 1940 they inspected the interior of the tank and found that all pitting and corrosion had been stopped completely. After this inspection, they metallized the entire exterior of a riser pipe with a coating of zinc followed by a coating of aluminum, then painted it for appearance. Now nine years after, the paint is peeling from washing. But even where it has peeled, the metallized coating is as sound as ever despite constant exposure. And, more important still, under the metallized surface, the steel pipe has not been attacked at all.

Many manufacturers of original equipment have adopted metallizing. It enables them to make a more corrosive-resistant product that permanently eliminates many maintenance headaches. One of the world's largest electrical manufacturers sprays 0.005 to 0.006 in. of zinc on its outdoor hanger-type capacitors, which provides a life expectancy of 15 to 30 years in rural atmospheres. Other production applications involve tanks, degreasers, refrigerator trucks and cold plates, barrels and many others. Write for your copy of the *Metco News*, Vol. 4, No. 12, Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

## Hard-Surfacing Electrodes

One of the most valuable products on the market for increasing the life of equipment is described in an informative folder now available upon request from the Stulz-Sickles Co., 134 Lafayette St., Newark 5, N. J.

Seaco AC-DC Hard-Surfacing Electrodes exclusively produced by Stulz-Sickles, protects those parts subject to severe impact and abrasion. Repairs made with Manganal and treated with Seaco Hard-Surfacing Welding Electrodes will outlast new parts.

## Selenium Rectifier D.-C. Welders

Booklet *DB 28-100* describing the new 200-, 300- and 400-amp., 60% duty cycle, selenium rectifier d.-c. welders is available from Westinghouse Electric Corp.

Included in this booklet is engineering information on these new welders, including relative power costs, performance characteristics, construction details, electrical characteristics, welding characteristics, dimensions and weights.

Power cost comparisons between these selenium rectifier welders and conventional motor-generator d.-c. welders are made for 33$^1/_3$ and 60% duty cycles.

Graphs of kva. input, efficiency and power factor at welding currents up to full load are included.

For a copy of this booklet write Westinghouse Electric Corp., Box 2099, Pittsburgh 30, Pa.

## Electrode Designation

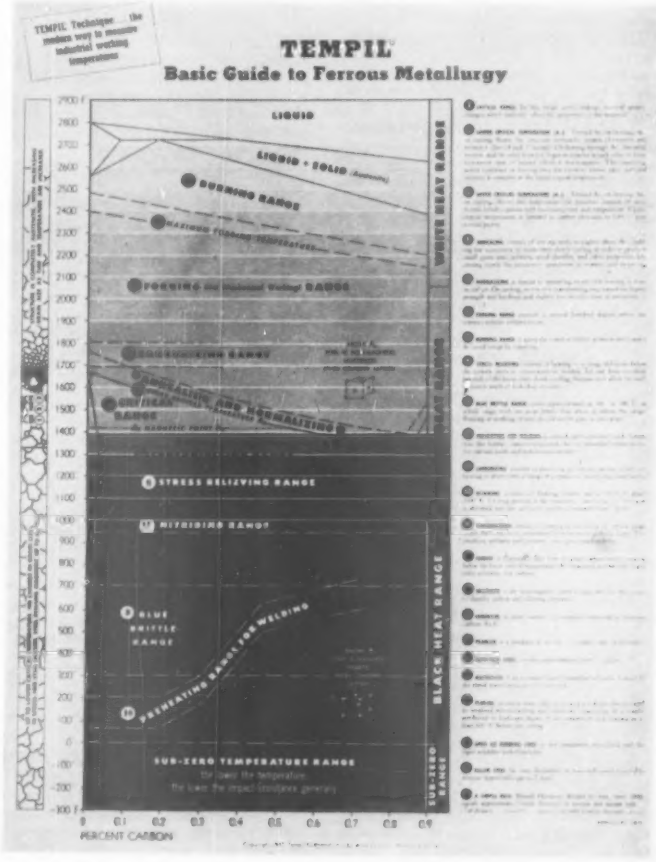
The Champion Rivet Co. of Cleveland, Ohio announces that their electrode formerly known as RAILEND is now called RAILENDER. There has been no change in color or operating characteristics.

## Guide to Metallurgy

Tempil° Corp. announces that a fourth printing of the Tempil° "Basic Guide to Ferrous Metallurgy" is now off the presses and again available.

This chart shows the working characteristics of steels in temperatures from −300° to 2900° F. All the important temperature zones, including hot-working, annealing, normalizing, stress relieving, carburizing and preheating for welding are clearly defined. Temperature ranges are shown in 19 colors approximating the characteristic hot-body radiant hues. At the right of the chart 23 fundamental metallurgical terms are defined and explained. A diagram symbolizing the change in grain size with temperature is shown at the left.

This handsome, plastic-laminated wall chart measures 16$^1/_4$ in. wide by 21 in. long. It can be cleaned easily and will last a lifetime. It provides a handy reference source for the engineer, metallurgist and skilled worker. Available without charge to industrial executives who request it on company stationery, stating their position. Address Tempil° Corp., 132 W. 22nd St., New York City 11.



# NEW PRODUCTS

## New Flux for Gold and Silver Soldering

A new liquid flux developed especially for use in gold and silver soldering operations has just been announced by Handy & Harman, 82 Fulton St., New York 7, N. Y. Copies of a descriptive bulletin are ready for distribution. Ask for Bulletin 18.

## Low Hydrogen Electrodes

A complete new line of low hydrogen electrodes is now being produced by Harnischfeger Corp., Milwaukee, manufacturer of P&H arc welders and electrodes. There are 14 different types in this new series, covering all welding applications where low hydrogen electrodes are desirable. Each has been thoroughly tested in P&H's laboratory and in their own welding production as well as in the field. The coatings were developed to produce deposits low in hydrogen, thereby eliminating the under bead cracking.

These new P&H electrodes produce excellent welds on problem steels and other alloy steels, including steel castings. They have a moderate penetrating arc with an easy to remove slag. Information in this new line of P&H low hydrogen electrodes may be obtained by writing Harnischfeger Corp., Welding Division, 4400 W. National Ave., Milwaukee 14, Wis.

## Welding Torches

The K-G Welding and Cutting Co., Inc. of New York City are introducing two new welding torches with cutting attachments. The smaller of these, the E50 Torch, has a welding range up to tip size 40—approximately $^1/_2$ in.; cutting range up to tip size 45—approximately 3 in. The larger torch, the K50, has a welding range up to tip size 20—complete welding range; cutting range up to tip size 40—approximately 6 in.

The mixer of the E50 Torch is used with nine sizes each of two different styles of tips. The torch hose connections have replaceable bushings for low-cost repair. The attachment (EA50) has a unique design, embodying an "O" ring of Neoprene, preventing gas leakage. No castings are used in torch or attachment. All joints are silver soldered except bushings and cone connector.

The K50 Torch has a solid Monel head in conjunction with brass seats in the mixer, assuring nongalling, positive seating. Swiveled conical needle valve seats of Tobin Bronze give perfect alignment in seating. Replaceable needle valve bodies reduce repair costs. The universal helical mixer accommodates all swaged tips from drill sizes 75 to 30 incl. All joints are silver soldered.

## Engine-Driven D.-C. Arc Welders

A new line of lightweight mobile engine-driven d.-c. arc welders, the WD-40 Series, has been announced by General Electric's Welding Division.

One of the five in the WD-40 Series consists of a general-purpose, heavy-duty welder, the WD-42AGW. It is driven by a 31-hp. Wisconsin VP-4 air-cooled engine with a magneto ignition. The welder weighs 1050 lb., and its rated output is 200 amp. at 40 v. A manually operated slow-down control economizes on fuel by slowing the engine to idling speed when not holding a welding arc. The WD-42AGW is designed for welding jobs requiring a heavier duty cycle and a good degree of portability, such as pipe-line operations. This heavy-duty, 200-amp. welder is also available with a four-cylinder, liquid-cooled Hercules engine-drive.

Other welders also in the liquid-cooled gasoline-engine drives are the WD-43AG and WD-44AG, powered by a six-cylinder, 36-hp. Chrysler industrial engine. The WD-43AG is rated at 300 amp. at 40v. and weighs 1725 lb. It is frequently used in the construction industry for welding beams and girders, and for general maintenance work.

The 400-amp. model, the WD-44AG, weighs 1775 lb. and has a welding range of 80–500 amp. Both models are equipped with belt-driven governors to prevent overspeeding of the engine and an automatic slow-down device to save gas.

The WD-40 series has four welders in the Diesel-drive line. The two 300-amp. models, the WD-43ADGM (General Motors Diesel engine) and WD-43ADC (Caterpillar), weigh 2350 lb. and 3350 lb. and have a welding range of 60–375 amp. In the 400-amp. line, the WD-44ADGM (General Motors) and WD-44ADC (Caterpillar) have a welding range of 80–500 Amp. All Diesel engines are equipped with batteries, generators, electric starters and preheaters to facilitate operation in subnormal temperatures.

## Stainless Steel

A new precipitation-hardening stainless steel with the strength and hardness of high-carbon spring steels and a corrosion resistance closely approaching that of 18–8 stainless has been developed by Armco Steel Corp., Middletown, Ohio. This new alloy, called Armco 17-7 PH Stainless Steel, not only broadens the field of application for stainless sheet, strip, plate and wire but has a unique combination of desirable properties never before available in a stainless alloy.

Excellent corrosion resistance, high strength and hardness, good elastic properties, fabricating flexibility and low-temperature hardenability give the new alloy unusual possibilities. 17-7 PH is especially recommended for use in the chemical, petroleum, textile and food-producing industries for springs, pressure tanks, diaphragms and disks, conveyor parts, spring clips, washers and similar parts. Its high strength and corrosion resistance also make it especially suitable for many applications in the aircraft and automotive industries. Of particular importance in these fields is the fact that the yield strength in compression is approximately equal to or higher than the yield strength in tension.

A wide variety of other recommended uses—carpenters' handsaws, bandsaws, measuring tapes, corset stays and fishing rods—indicates the versatility of 17-7 PH Stainless Steel.

The new stainless alloy is available in soft temper strip, sheet and plate; hard temper sheet and strip; and hard temper and extra hard temper wire.

In the soft temper condition, the alloy can be severely formed or drawn and welded by resistance, metallic-arc and inert gas shielded-arc methods. After fabrication, its full strength and hardness are developed by heating at 1400° F. for 30 min., air cooling and then heating to 900–950° F. for 30 min., followed by air or furnace cooling. Soft temper sheets when fully hardened have a tensile strength in the range of 185–205,000 psi., a yield strength of 160–190,000 psi. and a hardness of Rockwell C40–45.

Hard temper 17-7 PH sheet and strip have fabricating properties equal to Type 301 full hard-temper stainless steel. In this condition it can be punched, blanked, flanged and dished to a moderate degree. Tensile strengths over 255,000 psi. and Rockwell hardnesses over C51 are developed by simply heating the metal to 900° F. for 1 hr. and air or furnace cooling. Even higher strengths and hardness are possible in very thin gage material.

Hard temper 17-7 PH wire can be wrapped on its own diameter, indicating its adaptability to the manufacture of spring and spring-wire products. Properties quite similar to those of the best carbon steel music wire are developed by hardening at 850° F. for a minimum of 4 hr. and air cooling. Typical properties of Armco 17-7 PH wire after hardening are:

| | |
|---|---|
| Tensile strength, psi. | 260–345,000 |
| Yield strength, psi. | 250–340,000 |
| Hardness, Rockwell | C50 and up |
| Proportional limit in torsion, psi. | 150–180,000 |

Armco 17-7 PH wire is also available mill treated at 850° F. and in this condition is designated extra hard temper.

Since only low temperatures are required in the heat treatment of this new alloy, it has additional important advantages. The

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### *ALCOA DISTRIBUTORS NATIONWIDE:*

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**Baltimore, Maryland**
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**Boston (Cambridge), Massachusetts**
- Whitehead Metal Products Co., Inc.

**Buffalo, New York**
- Braco-Mueller-Huntley, Inc.
- Whitehead Metal Products Co., Inc.

**Charlotte, North Carolina**
- Edgcomb Steel Company

**Chicago, Illinois**
- Central Steel & Wire Company
- Steel Sales Corporation

**Cincinnati, Ohio**
- Williams & Company, Inc.

**Cleveland, Ohio**
- Williams & Company, Inc.

**Columbus, Ohio**
- Williams & Company, Inc.

**Dallas, Texas**
- Metal Goods Corporation

**Detroit, Michigan**
- Steel Sales Corporation

**Houston, Texas**
- Metal Goods Corporation

**Kansas City, North, Missouri**
- Metal Goods Corporation

**Los Angeles, California**
- Ducommun Metals and Supply Co.
- Pacific Metals Company, Ltd.

**Milford, Conn.**
- Edgcomb Steel of New England, Inc.

**Newark, New Jersey**
- Whitehead Metal Products Co., Inc.

**New Orleans, Louisiana**
- Metal Goods Corporation

**New York, New York**
- Whitehead Metal Products Co., Inc.

**Philadelphia, Pennsylvania**
- Edgcomb Steel Company
- Whitehead Metal Products Co., Inc.

**Pittsburgh, Pennsylvania**
- Williams & Company, Inc.

**Portland, Oregon**
- Pacific Metal Company

**Rochester, New York**
- Braco-Mueller-Huntley, Inc.

**San Francisco, California**
- Pacific Metals Company, Ltd.

**Seattle, Washington**
- Pacific Metal Company

**St. Louis, Missouri**
- Metal Goods Corporation

**Syracuse, New York**
- Braco-Mueller-Huntley, Inc.
- Whitehead Metal Products Co., Inc.

**Toledo, Ohio**
- Williams & Company, Inc.

**Tulsa, Oklahoma**
- Metal Goods Corporation

hardening process is not only simple and economical but cracking, distortion and decarburization, encountered in conventional heat treating, are virtually eliminated. In addition, there is no heavy scale formation to complicate finishing processes. The extremely light scale formed at 1400° F. and the heat tint produced at 850 and 900° F. are both easily removed by a 10% nitric–1% hydrofluoric acid solution.

Armco's 17–7 PH stainless steel, with their recently developed 17-4 PH stainless steel bar and forging grade, provides a complete range of mill products in these high-strength, precipitation-hardening stainless steels.

## Brazing Alloy Package

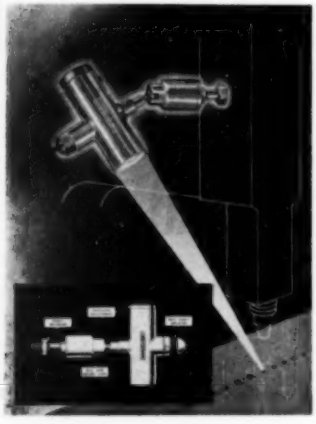
Handy & Harman have just announced a new silver brazing alloy package which should prove very convenient for many users of this product. It contains 5 oz. of $^1/_{16}$-in. diameter Easy-Flo-45 wire. "Torch Brazing Instructions" are included—also a "Quick Facts" folder telling the advantages you can gain by brazing with Easy-Flo 45.

This new package will be distributed through Handy & Harman's nation-wide dealer organization. A list of these dealers will be gladly sent on request.

## Locating Spotlight

This spotlight accurately locates work on all blind operations. The spotlight overcomes the difficulty of positioning large assemblies on all types of equipment such as resistance welders, automatic riveters, dimpling and countersinking machines, punch and drill presses and many other production equipment.

The spotlight is easily positioned on a ball and socket joint and the spot of the light can be adjusted to as small as $^1/_8$ in. diameter. The light is intense enough to be clearly visible under all sharp lighting conditions. It is a sturdily made unit, entirely chrome plated, with a special lens to permit a sharp definition of the spot in a wide range of diameters. It can be equipped with a transformer of 110 or 220 v., depending upon the line voltage required.



Bulletin No. 203-A describing this spotlight can be obtained by writing direct to Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill.

## Electric Arc Announces Regulating and Heating Units

Electric Arc, Inc., of Newark, N. J., announces the availability of its latest combination for preheating before welding and stress relieving after welding—the new 40-kva. Model RTA Regulating Unit and 40-kva. Model AC3 low-frequency Induction Heating Unit by the Smith-Dolan System.

This combination is designed for use in limited space where the extreme flexibility of Electric Arc's smallest induction heater is not needed (by this is meant their 10-kva. Model UP, which can be stacked in 10-kva. units to achieve 20 kva. capacity, 30 kva. capacity, etc.). The RTA Regulating Unit is arranged for operation on 220/440 and 550 v. at commercial frequencies. The AC3 Heating Unit is small enough to be placed near the work with easy accessibility.

With Models RTA and AC3 more equipment can be added as required, and when larger jobs are contemplated, the Model AC3 Unit can also be used as a booster unit with the other Smith-Dolan heating equipment, which is manufactured exclusively by Electric Arc, Inc. in Newark.

Automatic control cabinets, also made by Electric Arc, Inc. can be used with the Model RTA Regulating Unit.

Dimensions of the RTA Regulating Unit are as follows: 20$^1/_4$ in. wide, 31 in. deep, 29$^3/_4$ in. high and approximately 620 lb. in weight. Dimensions of the AC3 Heating Unit are: 35 in. wide, 32 in. deep, 46$^1/_2$ in. high and approximately 815 lb. in weight.

Further information on Electric Arc Induction Heaters and Control Instruments may be obtained by writing to the manufacturer for catalog material. Inquiries should be addressed to: Electric Arc, Inc., 152–162 Jelliff Ave., Newark 8, N. J.

## Low-Cost, Type D866 Welding Cable

General Cable Corp., 420 Lexington Ave., New York 17, N. Y., announces a new Type D866, low-cost welding cable.

This cable is light in weight which means less fatigue for the operator. Rope strand construction of No. 34 A.W.G. bright annealed copper plus green cellophone separator assures extreme flexibility and freedom of movement of the conductor within the rubber sheath and ready access to otherwise "difficult" spots.

Type D866 cable is resistant to sunlight, impact, abrasion and repeated flexing and guarantees continuous operation of welding equipment. Available from stock in sizes 6 to 4/0 A.W.G. in coils or on reels.

## Plastic Cover Plate

A new, clear plastic cover plate to protect costly welding plates from damage is announced by American Optical Co.

These new plastic plates—manufactured from methyl methacrylate, the material used for bombers' noses and navigators' turrets during the war—meet the optical requirements of the Federal Bureau of Standards.

The plates do not pit as readily from welding spatter as glass plates; are 0.060 in. thick assuring adequate impact resistance and will outlast ordinary glass cover plates many times over.

Two sizes available: standard, 2 x 4$^1/_4$ in., and a slightly smaller size, 2 x 4$^1/_8$ in., provided on special order.

## Automobile Battery Charger for Home Use

To anyone who has arrived late for work on a cold winter morning with the "dead battery blues," the announcement of a new automobile battery charger for home use will be of particular interest.

With a new special rectifier the "Lincwelder 60," a low-cost home arc welder manufactured by The Lincoln Electric Co., of Cleveland, Ohio, can be used for charging any of the standard 6-v. lead-acid automobile type batteries.

The "Lincwelder 60" operates off the standard house light circuit fused for 30 amp. so that now a low battery can be brought up or a dead battery restored to operating condition overnight at home. To charge a battery the welder and rectifier is simply plugged into a light socket and the leads clipped to the battery terminals.

***The "Lincwelder 60" home arc welder operating off the standard light circuit is used with a special small rectifier to recharge standard automobile batteries***

The "Linewelder 60" itself was introduced a short time ago as a new welder to operate off a 110-v. light circuit yet have a design and operating characteristics comparable to larger industrial welders. It is used in home workshops, repair shops, auto body shops and by sheet metal workers. In addition to battery charging and welding metals as thin as an automobile fender to 1/8-in. thick, the unit also can be used for soldering, brazing, cutting and heating metals. As a home workshop tool it is used for making home repairs to cars, metal furniture, broken metal parts and castings and for building shop and home equipment.

## Repairing Tanks

A common problem in many industries where toxic materials must be stored or handled is that of repairing tanks and other equipment by acetylene or arc welding. In some cases, even after all explosion and fire hazards have been eliminated, the element of toxicity remains or can be created by the heat of welding.

Now, after nine years of research and development, a device has been perfected that enables a welder to work conveniently and safely in atmosphere containing toxic vapors, dusts and fumes.

William A. Newman of the Safety Department of Ethyl Corp., in collaboration with representatives of several oil companies and Mine Safety Appliances Co., Pittsburgh, developed the protective equipment.

Although relatively simple, the device combines in one unit protection against ultraviolet and infrared radiation, impact and pitting and inhalation of toxic fumes. The facepiece assembly consists of an airtight rubber mask and chrome leather hood with flexible breathing tube connections.

Described as the most distinctive feature of the new device is the aluminum frame and flip-front assembly for holding the lenses. Three lenses are used—one is a permanent safety lens sealed in the assembly; the other two are removable welding and pitting lenses inserted in the flip-front. Different shades of filtering lenses can be used depending on the type of welding to be done. The flip-front enables the wearer to examine the work without interfering with the respiratory protection.

The new facepiece affords wide angles of visibility. It provides 81° lateral angle vision in contrast with only 60½° with the standard welding shield. The vertical angle of vision in the new facepiece is 37° against only 30° in the standard shield.

Although the unit weighs 8 oz. more than standard welding shields, it has improved weight distribution through the face and head supports. The distance the lift front holder protrudes is not as great as in standard masks. Both of these factors partially offset the additional weight.

When connected with an approved air line, the incoming air stream enters the mask at chin level and flows over the lens window to prevent fogging. Two spent air outlets at jaw level direct the air stream around the interior of the hood.

Development of the new facepiece was in answer to the problems encountered by the petroleum industry in the storage and handling of leaded gasoline. Ethyl's Safety Dept., with extensive experience in this field, was interested in providing means to repair gasoline tanks safely without the necessity of costly tank cleaning and preparing operations.

With the new mask, however, all that is needed prior to welding is to eliminate the explosion hazard in the tank and underlying soil. Welding operations then can be performed in a fraction of the time previously required as long as the new mask is used with an approved fresh air supply line.

## Removable Stops for Pallet Truck Forks

Many pallet truck users have more than one size pallet making it desirable to purchase a truck with forks designed to carry their longest pallets. When shorter pallets are handled, the operator must take time to spot the truck in the pallet, stopping at a certain point to be sure that the rear wheels of the truck will drop through the spacing in the bottom boards.

A bar with two pins or legs has been designed so that it can be dropped into holes set at fixed points in the truck frame, thus the forks can be quickly fitted to any number of popular size pallets. The stop limits the distance the forks can enter and the rear wheels of the truck are always spotted for perfect operation.

Lyon-Raymond offers this new removable stop as an optional accessory to their entire pallet truck line.

When the stop is not in use it is carried in a convenient holder on the pallet truck head frame.

Write to Lyon-Raymond Corp., 23665 Madison St., Greene, N. Y., for complete information about the new stop bar.

## Work Holding Clamps

Two new heavy-welded duty clamps have been developed by General Welding Corp., of Cleveland, Ohio. They resemble other standard General toggle clamps in their rugged, all welded construction. Heavy bar stock is featured in all models.

The plunger type clamp, Model D-2, shown in the photo (top) employs a bronze plunger. The advantage to the user is that weld spatter will not adhere and foul up the clamp's operation. An extra long stroke, 1¾ in., is provided. Pressure is 700 lb.

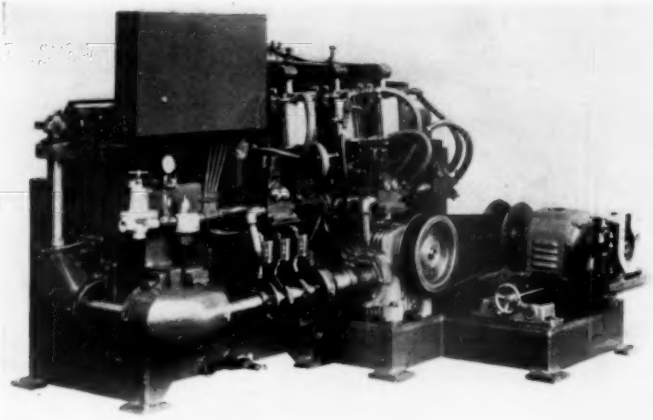
Model C-2, shown at the bottom in the photo, is a horizontal type toggle clamp. It is recommended especially for milling and drilling operations. Pressure rating is 1000 lb., although much higher pressures may be obtained by shortening the work bar.

## Dual Flash Welder

A new heavy duty 75 kva. special dual flash welder designed for high-speed fabrication of wringer roll assemblies for washing machines was recently developed by the Federal Machine and Welder Co., Warren, Ohio. Capable of turning out finished parts at the rate of 400 to 450 per hour, the welder incorporates several important features including:

1. Compactness of drive. Use of a standard Cone-Drive double-enveloping geared 40-to-1 speed reducer of only 4 in. center distance takes care of the high maximum upset force of 4500 lb. at each end. Double extended output shaft facilitates power transmission to upset cams at each end of welder.

2. Heavy ball bearing mounted steel shafts with enclosed bevel gears transmit



maximum torque of 3000 in.-lb. from Cone-Drive reducer to each upset cam.

3. Quick acting pneumatic clamping with trunnion-mounted double acting air cylinders. Adjustable, self-aligning upper dies furnish 7000-lb. clamping pressure.

4. Completely automatic machine cycle, except for loading and unloading of parts.

5. 2 hp., 440 v., 1200 rpm., 60-cycle motor equipped with Reeves variable speed pulley and solenoid operated brake for accurate control of welding and upset cycle.

6. Easily adjusted cams for actuation of cycle control switches are coupled to Cone-Drive output shaft.

7. Eight-point heat controls for both welds.

8. Patented side bar platen guides to insure accurate alignment of welded parts.

9. All moving parts are equipped with grease fittings for lubrication.

In operation, the tube which forms the wringer roll is placed on the lower dies at the center of the machine, and the cold-headed trunnions which are to be welded to the ends of the roll are inserted into fixtures mounted on sliding platens. Pressing the start button causes the upper dies to drop, clamping the parts. The sliding platens are then forced inward by cams, the weld completed, part released and platens withdrawn by air pressure. The completed wringer roll is then unloaded.

## Electrode Comparator Slide Rule

A new pocket-sized G-E welding Electrode Comparator slide rule chart (Publication No. GEN-37) has been announced as available from the General Electric Co., Schenectady 5, N. Y.

This handy comparator slide rule lists all of G.E.'s welding rods and electrodes and indicates the type of service for which each is designed. All principal manufacturers' electrodes which are the closest equivalents for the application noted for G.E.'s rod are also listed. Listings are suitably keyed to A.W.S. classification numbers and comparison data may be read directly off the slide rule.

For the convenience of the operator the A.W.S. class designations are explained on the back of the comparator slide rule to simplify selection of electrodes.

## Cast-Iron Electrode

Eutectrode 24 "Formula 1950" has undergone many new improvements.

First, the amperage required for running this electrode has been substantially reduced. For example, the $^5/_{32}$-in. size which normally requires 120 to 125 amp., can now be readily deposited on the same thickness of metal at only 80 to 90 amp., further reducing the risks of stress and distortion. The arc stability, the rate of deposition and the flatness of the bead are unmatched by any other rod previously made.

Spatter is nonexistent, and most important for the operator is the ease with which the flux can be removed. No chipping hammer is required—a brush will remove it. The deposited metal is of extreme density, free of porosity and cross checks and machinability is excellent. Tensile strength is 50,000 psi.; hardness is 150-200 Brinell.

Eutectrode 24 "Formula 1950" is an invaluable aid in repairing and salvaging machinery and equipment. It is especially useful for welding cast iron to cast iron, cast iron to steel and for repairing machining and foundry defects. Available in sizes of $^1/_{32}$, $^1/_{8}$, $^3/_{32}$ and $^3/_{16}$ Eutectrode 24 "Formula 1950" is also made in special $^1/_{4}$-in. size for welding heavy castings. For free descriptive booklet write to: Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.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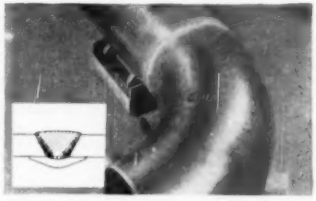
*Tacking completed, spacer pins are knocked off and the welder finishes his joint. Insert shows cross-section of ring and joint.*



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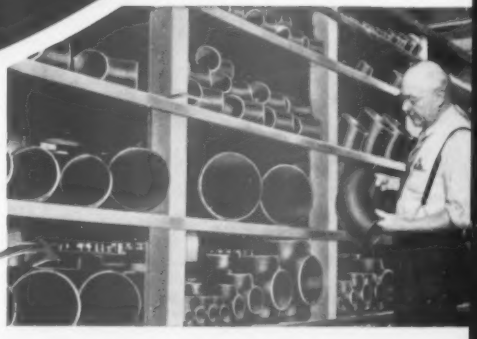

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# SECTION ACTIVITIES

*prepared by C. M. O'Leary*

### *Anthony Wayne*

The January meeting of the Anthony Wayne Section was held on Friday, January 13th, in the Fort Wayne Chamber of Commerce Building. Following a Buffet Dinner a new 16 MM sound film entitled "Unfinished Business" was shown through the courtesy of the United States Steel Corp.

The principal speaker at the technical session was H. T. Smith, Development Engineer, The Linde Air Products Co., Chicago. Mr. Smith gave a most interesting talk on "Unique Applications of Oxygen." He showed colored movies along with his talk which covered such unusual uses of oxygen as fusion-piercing of blast holes in mining; powder cutting of stainless steel, cast iron, heavy skulls, spills and thimbles; open-hearth furnace operations; electric furnaces; foundry cupolas, etc.

The March meeting scheduled for the 17th will be a "Quiz the Experts" Program to which the Indiana, Detroit and Western Michigan Sections are sending teams to compete with the Anthony Wayne Team.

### *Arizona*

The regular meeting of the Arizona Section was held in the Aluminum Room of the Westward Ho Hotel, Phoenix on the evening of January 18th.

The Section was honored with the presence of Frank Brandt, Assistant Sales Manager, Thomson Electric Welder Co. of Lynn, Mass. Mr. Brandt gave a very instructive talk accompanied by slides, showing "Modern Trends in Resistance Welding." His lecture prompted a lively discussion which completed the evening. All present felt that they learned something from the lecture.

### *Birmingham*

The January meeting of the Birmingham Section was held on the 12th at the Redmont Hotel. Forty-two members and guests heard Raymond C. Freeman, Manager of Engineering for the Welding Division of General Electric Co., present an interesting talk on the "Merits of A.-C. vs. D.-C. Welding."

Mr. Freeman's competent manner of presentation and his comprehensive coverage of his subject assured an interesting evening for all present. A lengthy discussion period followed the talk, during which time Mr. Freeman elaborated on some points of special interest to the members and answered many questions.

### *Boston*

The regular monthly dinner meeting of the Boston Section was held on January 9th in the Campus Room, Graduate House, M.I.T.

The dinner speaker, John G. Stilli, Sales Promotional Manager, Station WBZ, Boston, gave an illustrated talk with movies on "Television" which was very well received. Technical speaker was Edward H. Roper, Air Reduction Sales Co., New York City, who spoke on a new welding process "The Aircomatic Welding Process." This was well presented and greatly interesting to those present. Slides were used to illustrate the talk. Sixty-seven members were present.

### *Chicago*

Dinner meeting was held on January 20th at Burke's Grill. A film "Wings Over Viking Land" was shown through the courtesy of American Airlines. An interesting and beautiful picture of an airline vacation trip to Norway, Sweden and Denmark.

Speaker at the technical session was E. S. Wheeler, District Manager, Shawinigan Products Co. Mr. Wheeler traced the history of the Carbide Industry from its inception to the present day. An interesting fact was that many of the questions following the presentation pertained to proper and improper use of carbide and generators.

### *Cincinnati*

A Resistance Welding Forum sponsored by The Precision Welder & Machine Co. was held on Tuesday, Nov. 22, 1949, at Engineering Society Headquarters. Moderator was E. W. Forkner, Vice-President in Charge of Operations of The Precision Welder & Machine Co.

About a ten-minute period was devoted to each of the following topics by the speakers. Following these talks an open discussion was held on the subject in general with specific problems being answered by the panel of experts.

"Maintenance of Resistance Welding Machines," Ralph Pelton, Welding Engineer.

"Power Supply and Control for Resistance Welding Machines," William G. Bostwick, Chief Electrical Engineer.

"Design and Application for Resistance Welding Machines," Carl Bertsche, Sales Engineer.

The Forum was very well conducted by Mr. Forkner and the question and answer period following the talks was very ably handled by the men on the Forum.

Lew Gilbert, Editor of *Industry and Welding*, was the speaker at the January 24th meeting. Mr. Gilbert presented a very good clear-cut picture of some phases of maintenance welding in industry which are not ordinarily associated with welding. A 16 mm. film showing various welding jobs was shown.

Following the meeting a "Dutch Lunch" was served to all members and their guests.

### *Cleveland*

Mrs. Cloyd W. Kerlue was the dinner speaker at the January 11th meeting held at the Cleveland Engineering Society. Mrs. Kerlue's talk on "Obedience Training" was very well received.

Technical speaker was C. B. Stadum, Westinghouse Electric Corp., who presented an illustrated address on "Electrical and Welding Advantages of 3-Phase Convertor."

May 12, 1950, Hollenden Hotel, is the time and place of the first of a new series of annual symposiums by the Cleveland Section.

This eleventh symposium will be the first of a new series. It will offer a complete gas, arc and resistance program. The speakers have been very carefully chosen.

The principal evening speaker will be the Countess Maria Pulaski of the Polish Royalty. During the war the Countess was a British spy in enemy territory. The Countess is quick-witted with a keen sense of humor.

The Section chairman will be assisted by Stuart P. Cramer, as toastmaster at the evening meeting.

The much greater cost of the 1950 Symposium to the contrary notwithstanding the cost of the dinner tickets including registration, will be the same as previous years: $4.50 each, $45 for a table of ten.

Esther Mullin was the feature of the Ladies' Night Program held on February 8th at the Hotel Allerton Main Ballroom. Her talk "Two Sides of a Microphone" was enjoyed by all. Miss Carol Ann Elder, daughter of the Chairman, C. T. Elder, played the piano for the community sing and also gave a short piano recital. Free Buffet refreshments were served at 9:00 P.M.

### *Colorado*

Regular monthly dinner meeting of this Section was held on January 12th at the Silver Wing Inn, Denver.

Anthony K. Pandjiris, President of Pandjiris Weldment Co., gave an extremely interesting talk and capably

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showed the many advantages of Weldment design. His very forceful manner of speaking was an inspiration to all.

Following the technical session an Army-Navy Football picture was shown.

### *Columbus*

Monthly dinner meeting of the Columbus Section was held on Friday, January 13th at the Fort Hayes Hotel.

Pre-meeting feature was the showing of color slides of the Far East by Walter Hanes, Chairman of the Section.

Technical speaker was Wm. Farrell of Sciaky Bros. Inc., who covered the subject "Resistance Welding as Applied to Low Pressure Vessels and Structural Welding."

Mr. Farrell excited considerable comment with the use of very high currents for resistance welding both light gages and up to $\frac{1}{2}$-in. plate for structures.

The structural resistance welding evoked a lot of interest and Mr. Farrell was quite busy answering a great many questions.

Three-phase d.-c. current with extremely high currents, up to 130,000 amp., are a criterion to good welds on heavy sections.

Mill scale, up to now a deterrent to good welds is no longer a nemesis. By applying a combination of high current, preheat, postheat and high pre- and post-pressures welds good sound welds are achieved with a joint efficiency up to 90%.

These were a few of the points brought out by Mr. Farrell's talk.

### *Dallas*

The Dallas, Texas Section held its January meeting on the 18th in the Auditorium of the Mercantile National Bank. Dinner at Earl's Steak House preceded the meeting.

N. G. Schreiner of The Linde Air Products Co. gave a very informative talk on "Developments in Automatic Welding," which was well received by the members present.

### *Dayton*

"Why Not a Universal Electrode?" was the topic of discussion at the January 25th meeting held in the Dayton Engineers Club. Orville T. Barnett of Metal & Thermit Corp., in his technical address gave the group a very thorough answer in showing why a universal electrode was impractical. He listed the various A.W.S. electrode classifications for low-carbon steel and discussed each one in detail. For each classification, he traced its development, listed its characteristics and applications and outlined its popularity. The address and discussion which followed did much to clear up the confusion which exists in many electrode classifications and trade name designations.

Mr. Barnett also showed a sound color movie on "Mass Production of Massive Parts," showing how thermit welding is used on a production basis in shipyard, locomotive and similar work.

In a short ceremony before the technical session, Chairman John Blankenbuehler presented Past-Chairman pins to three members and cited their contribution in organizing and making a success of the Dayton Section. They were Al Mealey, Carl Smith and Ben Hausfeld.

The meeting was concluded with a social hour with refreshments.

### *Detroit*

Discussions on Open Arc Welding were presented at the January 13th meeting held in the Engineering Society of Detroit.

Speakers were Joseph H. Humberstone, President of Equipment Mfg. Div., Air Reduction Sales Co., and R. David Thomas, Jr., Vice-President and Director of Research and Engineering of Arcos Corp. Their subjects were Low-Alloy Steels and Stainless Steels, respectively.

These discussions were well illustrated, clearly presented and stimulated considerable discussion following their presentation.

### *Hartford*

"Automatic Welding" was the subject presented by J. M. Tippett at the January dinner meeting held on the 12th at the West Hartford-Rockledge Country Club.

### *Indiana*

The January dinner meeting of the Indiana Section was held on the 27th at Buckley's Restaurant, Cumberland, Ind.

Prior to the presentation of the technical speaker some Section business was transacted, including the appointment as delegates to the Purdue Welding Conference of E. O. Smith, Wilhelm Pollock and Ray Wirt. Two new members, Mr. Lewis of Precision Welder and Mr. Plemon of J. D. Adams were introduced and Chairman Smith gave a talk on the membership drive. Visitors present included Robert Cobert of the Dayton Section and two members from the Tool Engineers Society.

Technical speaker was F. E. Garriott of Ampco Metal, Inc., Milwaukee, Wis. Mr. Garriott presented a clear cut, interesting talk on "Welding with Bronze Electrodes." A film "Golden Horizons" was shown in conjunction with the talk.

### *Kansas City*

Dinner meeting of the Kansas City Section was held on January 9th at the Advertising and Sales Executive Club.

Anthony K. Pandjiris, President of Pandjiris Weldment Co., gave an enlightening talk on the subject Weldment Design. Mr. Pandjiris presented his talk so that both the engineer and shop man could readily understand.

### *Lehigh Valley*

John H. Berryman, Assistant to the Manager of the Technical Sales Division, Air Reduction Sales Co., was the guest speaker at the January 9th meeting held at the Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa. Q. E. Charlesworth, Section Chairman, presided at the meeting.

Mr. Berryman gave an illustrated talk on the "Aircomatic Process," discussing the development of this gas-shielded metal-arc welding process. He told of combining the features of both metal-arc welding and inert-gas-shielded arc welding, this process having been developed primarily for the welding of aluminum and its alloys, but it has been used successfully for the welding of stainless and mild steels.

Following the technical session there was a demonstration of the Aircomatic process under the direction of William Benz, Welding Technician, Air Reduction Sales Co.

The February dinner meeting was held on the 6th in the Hotel Bethlehem. A "Panel Discussion" followed the dinner, at which time Q. E. Charlesworth, Section Chairman, acting as Moderator, introduced the following members of the panel: Wayne Price, Air Reduction Sales Co., Earl David, Heilman Boiler Works; Fred Snyder, Metal Welding & Supply Co.; Joseph Kenworthy, Mack Manufacturing Co.; Gilbert E. Doan, Lehigh University and R. A Bartholomew, Lehigh Structural Steel Co.

The discussion period covered all phases of welding. It proved to be a very interesting discussion with many of the members and guests taking part in a question and answer period.

### *Long Beach*

The first 1950 meeting of the Long Beach Section was held on January 20th, called to order by Gail Beckstrand with 42 members present.

The first order of business was discussion through the question and answer period, also the filling out of questionnaires.

The main speaker of the evening was Hugo W. Hiemke and his talk was "New Application of Welding in Southern California," accompanied with interesting slides.

Membership Chairman Malton Teeter, introduced four new members and each member present pledged a new member by the next meeting.

### *Louisville*

Edward H. Roper, Assistant Manager of Air Reduction Sales, Technical Sales Division, was the guest speaker on January 31st. His talk was a discussion of a new process and equipment for making inert-gas-shielded metallic-arc welds.

By using the blackboard, a movie film and a series of slides, Mr. Roper described the method of operation of the equipment and told of the advantages of using a consumable electrode with the inert-gas shielding. He stated that with this process high-quality welds were produced without the use of flux and that cleaning and finishing was reduced to a minimum. He said that for aluminum and its alloys the welding is very rapid and less weld metal is required because the joint openings can be narrower than for other methods.

The evening closed with a social hour and a Dutch lunch.

### *Maryland*

The second half of the present season of the Maryland Section was started auspiciously with a dinner attendance of 41 on January 20th, at the Engineers' Club, Baltimore. The after-dinner "talk" was given over to a demonstration of glass-blowing by J. J. Madine, technician in laboratory glass work.

The members appreciated the common denominator of glass blowing and welding; namely, skill and dexterity. Employing an uncommonly high degree of perfection, these qualities created first a utilitarian piece of laboratory apparatus and then an artistic ornament. The technical session was covered by a talk by Arthur N. Kugler of the Air Reduction Sales Co., New York, who initially described the various processes using inert gases as a shielding medium by enumerating their individual characteristics. On this basis the talk illustrated how the most favorable traits of different methods were combined to evolve a process and devices which jointly satisfy the demand for a semiautomatic or fully automatic method of welding the heavier sections of those alloys which cannot be welded economically, or with satisfactory quality, by coated electrodes.

The audience of about 90 persons participated in a vigorous discussion which was terminated rather by the lateness of the hour than by lack of interest.

### *Michiana*

The men of the Michiana Section showed their ladies that the AMERICAN WELDING SOCIETY means more than just a night out when they were entertained at the first Ladies' Night the Section has ever held. A dinner and a rose started the evening, with a very interesting discussion of "Synthetic Gem Stones" by John P. Skinner, District Sales Manager, The Linde Air Products Co., forming the "piece de resistance." Perhaps the highlight of the evening, at least for one lady, was the drawing for the door prize—a synthetic ruby, cut and ready for mounting.

Mr. Skinner traced some of the history and terminology of gem stones, including how Linde happened to get into the business of making these synthetic stones.

While a few of these stones are now being made into gems, most are turned to industrial uses, such as bearings, in delicate instruments, including watches. Of the gems now being made, the two most interesting are the star sapphire and titania. The former is extremely rare in nature and a properly polished stone is a thing of exceptional beauty.

Samples of the various synthetic stones described were shown in the raw and cut stages. While this seems somewhat far afield from welding, it made a very interesting and informative meeting.

### *Milwaukee*

The January meeting of the Milwaukee Section was preceded by a well-attended buffet dinner. A colored movie, film was presented by a member of the Milwaukee Public Museum Staff for the coffee talk. This beautiful film was taken during a summer cruise of the Great Lakes and the St. Lawrence River, and it certainly routed all thoughts of the near zero weather outside.

The technical speaker was L. E. Kunkler who gave a history of the process of metallizing from the very beginning up to the most modern applications. This talk created a surprising amount of interest in the group and Mr. Kunkler was answering questions long after the meeting had been closed.

The first two meetings of the annual Educational Course have now been presented. The first meeting was held on January 23rd and the second on January 30th. K. Jackson of the Caterpillar Tractor Co., Peoria, Ill. was the first speaker and he devoted most of his attention to the value of jigs and fixtures in producing precision weldments.

D. C. Smith of the Harnischfeger Corp. was the second speaker. His talk was an explanation of the metallurgy involved in welding as it affects the welder and his work.

There was an excellent attendance at both of these meeting; about 250 each evening.

During the month of January the Section enjoyed a visit from the National President of the SOCIETY, O. B. J. Fraser. Although Mr. Fraser could not attend the monthly meeting, the Section Officers and Directors did have an opportunity to lunch with him. Mr. Fraser's discussion of the problems of the SOCIETY as a whole and the membership problem in particular was of interest and helpful to the Section.

### *New York*

The New York Section held its first meeting in the new year on January 10th. The meeting was preceded by a dinner at Schwartz's Restaurant, where all the meetings to date this season have been held. Immediately after dinner, a motion picture entitled, "Conquest of the Hudson" was shown through the courtesy of The Port of New York Authority. This film portrayed the various stages of planning and construction of the Lincoln Tunnel.

Erwin C. Brekelbaum, Executive Chief Engineer, Harnischfeger Corp., Milwaukee, Wis. was the principal speaker. The subject of his talk was "Maintaining Weld Quality Through Production and Quality Control." Mr. Brekelbaum stressed the importance of proper coordination of the engineering, production planning, production and inspection departments to obtain efficient and economical operation. As a first step in this direction, Mr. Brekelbaum advocated the training of the design engineers in making proper drawings for welding. He discussed the means by which his company accomplishes this end, and displayed a copy of the Engineering Standards Book they have compiled to guide their Engineering Department. Mr. Brekelbaum stated that the Harnischfeger Corp. makes wide use of the A.W.S. Code on Standard Welding Symbols, and he described how they had extended the usefulness of these symbols for their purposes by adding more information to the basic symbol within the "fishtail" of the arrow.

Following the presentation of the technical paper, a lively discussion was held. Problems encountered in the engineering and production fields were discussed, as well as matters pertaining to the usefulness to industry of the A.W.S. Codes and Standards. Many members of the audience participated in this highly interesting discussion period.

E. B. Stolie was the Technical Chairman of the meeting, and adroitly conducted the discussion period at the conclusion of the technical paper.

### *Niagara Frontier*

This Section held its January dinner meeting on the 26th at the Sheraton Hotel, Buffalo, N. Y., with an attendance of 60 at the dinner and 80 at the technical meeting.

I. Morrison of the Morrison Steel Products, Buffalo, was the dinner speaker. Mr. Morrison spoke on the membership and on the March of Dimes.

Technical speaker was Norman G. Schreiner, Mgr., Service and Development, Unionmelt Division, The Linde Air Products Co., New York. Mr. Schreiner's subject was "The Effect of Various 'Flux' and Electrodes Compositions on Submerged Arc Welding." His talk was well illustrated and described the welding behavior for each type of "Unionmelt" and the welding conditions suitable for each melt were covered.

### *Northern New York*

This Section held its monthly meeting on January 26th at the Circle Inn at Lathams, N. Y. A well-attended dinner heard J. G. Magrath, National Secretary, as after-dinner speaker. Mr. Magrath's talk was both inspiring and informative on the support, activities and future of the SOCIETY.

The technical speaker for the evening was R. J. Metzler, service engineer for Handy and Harman. His talk was entitled "Production Applications of Silver-Alloy Brazing" and covered the fundamentals of brazing as well as numerus examples of production problems and solutions. A new motion picture on Silver-Alloy Brazing produced by Handy and Harman was shown for the first time in the East to an A.W.S. Section. It is recommended by all who saw it.

### *Northwest*

The Northwest Section held no technical meeting in December. However, on December 9th the Section held its first Christmas Party. Some 50 couples attended the dance and buffet supper held at the Hotel Francis Drake in Minneapolis. Awards were made at that time to Ray Schwabe's winning team in the membership contest. S. H. Olson was the leading member procurer on this team.

The monthly meeting for January was held on the 9th at the Covered Wagon in Minneapolis. An address was made by C. M. Sheridan, Associate Director of Research for Allegheny Ludlum Steel Corp. at Brackenridge, Pa. Mr. Sheridan spoke on the subject of "The Welding of

Stainless Steel." Mr. Sheridan first explained the developments of stainless steels and the various types as to their contents covering the varying amounts of Chromium, Nickel and Carbon.

Various slides were shown illustrating grain structure as well as crystallization and the effect of heat treatment on ductility of various specimens.

The lecture concluded with the discussion covering carbide precipitation in welding zones and the amounts from the different types of welding. The general question and answer forum followed the meeting.

Host for the Happy Half Hour preceding the dinner was O. J. Karnavoski, representative of Joseph T. Ryerson & Sons Co.

## Oklahoma City

The January meeting was held on the 17th in the Mirror Room of the Biltmore Hotel. Several noted visitors were present and a great deal of interest and enthusiasm was shown.

The speaker was Dr. Waldo E. Stephens who spoke on the subject "False Security." He is one of the most widely informed men in the southwest on the national status of our Government from an economical standpoint.

Dr. Stephens served in France during World War I and later spent several months in England, Germany and France conferring with these three powers on Postwar policies. He also toured the industrial and shipping centers in Asia and Europe. One of his published works is "Revisions of the Treaty of Versailles." He is a member of numerous committees dealing with world government, foreign policy and peace measures.

This program was far removed from the general type presented. The speaker's subject had nothing to do with welding either directly or indirectly; but it was well received and enjoyed by everyone in attendance.

## *Philadelphia*

The Annual Joint Meeting of the Philadelphia Section of the American Welding Society with the Philadelphia Section of the Society of Naval Architects and Marine Engineers as the host society this year, was as usual an outstanding success. The large crowd present was indicative of the many common interests between the members of the two societies.

J. Lyell Wilson, formerly with the American Bureau of Shipping as Director of Research, spoke on "Research and Developments in Modern Steels for Ship Construction." His participation in the research program investigating ship steels during and following World War II has given him a thorough knowledge of the suitability of steels for ship construction. In the short time allotted to him, Mr. Wilson did an excellent job of bringing all those present up-to-date on steel developments and the suitability of steels for welding.

Following the usual custom of the Naval Architects, the discussion was guided by Harry W. Pierce, First Vice-President of the A.W.S., as meeting co-ordinator, and started with prepared discussion from F. H. Pennell, Metallurgist, DeLaval Steam Turbine Co. and Captain Wendell P. Roop, U.S.N. (Ret.) associated with Swarthmore College. The informal discussion that followed indicated the general interest of those present.

The Panel Discussion meeting on "Welding and Fabrication of High Temperature High Pressure Power Plant Piping" which was held on Wednesday, February 1st, reached a new high for popularity. An overflow crowd of nearly 150 jammed the Dining Room of the Engineers Club.

William Manson, Piping Supervisor, and James Gleason, Jr., Welding Engineer, of United Engineers and Constructors, Inc., acted as the leaders of the Panel to introduce the subject and answer the questions that arose from the assembled group. The discussion and questions which continued for nearly two and a half hours were extremely informative and helpful.

One of the big events of the year is scheduled for Monday, March 20th, when the Philadelphia Section will be host to the Maryland, Lehigh and Washington, D. C. Sections in the "Battle of the Sections." The teams, of high caliber for each Section, are expected to make the judge's decision a hard one.

## *Pittsburgh*

The regular monthly dinner meeting of the Pittsburgh Section was held on January 18th at the Hotel Webster Hall and the Mellon Institute.

Business matters, including the presentation of a "Norma" pencil to the speaker, were handled before the technical session. A committee meeting was held following the speaker to discuss arrangements for the Tri-State Meeting on April 28, 1950.

Dr. M. Gensamer, Assistant to Director of Research, Research and Technology Dept., Carnegie-Illinois Steel Corp., presented an illustrated discussion on "Steel Under Stress." A film "Making and Shaping of Steel" was shown in conjunction with the address. An attendance of 110 members enjoyed the presentation.

## *Rochester*

The Rochester Section held its monthly meeting on Monday, January 16th. A dinner preceded the meeting. Chairman Walter Kazoroski opened the meeting by introducing the new members. A sports movie, "Sun Valley Ski Chase," showed the "Hound and Hare" ski chase through this famous and dazzling ski country.

The guest speaker for the evening was Clyde Martin of Wm. J. Meyer Co., Rochester, N. Y. His subject was "Light Gage Welding." Mr. Martin reviewed the history of welding and pointed out the tremendous progress in machines, materials, methods and procedures during the past 25 years. He emphasized the need for cooperation between the engineering and fabrication departments. The importance of selecting the type of welding to be used was cited as a prerequisite to the designing of a part. Here is pointed out the advantages of various types of welding and joint design. A lively discussion followed.

## *Saginaw Valley*

The following are the reports on regular monthly meetings held by the Saginaw Valley Section since the start of the 1949–50 season.

Sept. 8, 1949—Two plant tours. Tour No. 1 to Electric Auto-Lite Co. This plant builds auto horns, grilles, decorative trim, plastic products, speedometer cables and many other parts. Spot, Seam, Projection and Stud welding operations were feature attractions of the evening. Very well liked.

Tour No. 2 to Bay City Shovels, Inc. The arc welding of heavy-fabricated parts used in the manufacture of the famous Bay City Power Shovels.

Dual plant trips are the exception but this one worked out very well as it provided a program of interest to all types of members. Members made one or both tours as they desired. This is an excellent way of touring smaller plants or plants with only special welding interests which would not take all of one evening. Serving of coffee and doughnuts in the cafeteria to members between tours was an excellent way to get the group together and provided a resting spell. Refreshments were provided by Auto-Lite.

Oct. 6, 1949—Plant Tour of the Simplicity Engineering Co. Manufacturers of shakers, oscillating-type conveyors and foundry equipment. This arrangement works very well where a good place to hold a dinner meeting is near the plant to be visited. This enabled the Section to take care of Section business at the same time. Dinner was enjoyed in the Family Cafeteria.

Nov. 10, 1949—Dinner meeting at McNivens Hotel, Frankenmuth, Mich. Technical speaker was Martin P. Korn, Consulting Engineer, Giffels and Valet, Inc. Mr. Korn held the audience all through his presentation and was well received. His subject was "Creative Design with Welded Rigid Frames."

Annual Christmas Party was held on Saturday, December 10th, at White Birch Hills Country Club, Alburn, Mich. Dean Knight, of National Electric Welding Machine Co., and Irving Mattson served as co-chairmen.

At 7:00 P.M. the party of 58 gathered around a punch bowl for an hour of conversation. An excellent dinner was served at 8:00 P.M., following which door prizes were distributed. The grand prize, a radio, was drawn by John Clayton.

Irving Mattson assisted the orchestra with his saxophone and clarinet for dancing which ran into an overtime session while others of the party enjoyed various card games.

All who attended voted the party a complete success.

Jan. 12, 1950—Dinner meeting at McNivens Hotel, Frankenmuth, Michigan. Speakers were A. Clemens, Jr., Research Engr., Arcrods Corp.; whose subject was "Welding of Low-Alloy Steel," and R. D. Thomas, Jr., Director of Research & Eng., Arcos Corp.; whose subject was

"Welding of Stainless Steel." Very well presented. Present were Detroit Chairman, T. J. Crawford, C. E. Phillips and Bill Walker.

### *Salt Lake City*

January 12th dinner meeting held at Hotel Temple Square, Salt Lake City, Utah. Dinner speaker was Vadal Peterson, Head Basketball Coach at the University of Utah, who told about basketball games at St. Johns and Madison Square Garden.

Technical speaker was Prof. A. B. Kemp, Utah State Agricultural College, Welding Dept., who spoke on what college can do for the welding profession.

### *Susquehanna Valley*

The third meeting of the 1949-50 season was held Wednesday, December 7, 1949 at the Hotel Sterling, Wilkes-Barre, Pa. F. L. Brandt, Asst. Sales Manager, Thomson Electric Welder Company, Lynn, Mass., spoke on the subject of "Resistance Welding".

The dinner was followed by sound movies of the Bikini atom bomb tests furnishing a timely topic for Pearl Harbor Day. This film was only recently removed from the restricted list and made available to the public.

Mr. Brandt spoke of the chief factors which afford sound resistance produced weldments covering power, pressure and electrodes. His talk included illustrations depicting a great variety of resistance welding machines all designed to perform specific jobs.

Mr. Brandt described the differences of butt, flash butt, and synchomatic welding machines and had samples to show actual production weldments. Mr. Brandt concluded by giving the many production welding people present a rule of thumb theory that the upset pressure used in resistance welding equals 70 per cent of the ultimate tensile strength of the material being fused to produce optimum strength welds.

A question and answer period followed.

Dinner meeting held at Hotel Berwick Ball Room, Berwick, Pa., on January 4th. John Hewitt entertained the dinner guests with humorous short stories which were thoroughly enjoyed. Technical speaker was G. E. Bellew, Steel Mill Specialist of Airco, whose subject "Cutting, Gouging, Scarfing" was well received, as well as a film, "Flux Injection Cutting."

The April meeting is scheduled for the 5th of April. E. C. Korten of the Hartford Steam Boiler Inspection & Ins. Co., will speak on "Boiler Codes."

### *Western Massachusetts*

On Tuesday evening, January 16th, the Western Massachusetts Section held a joint meeting with the American Society for Metals at the Hotel Sheraton in Springfield. Dr. Ernest Nippes of Rensselaer Polytechnic Institute, reviewed the work being done on Weldability of Steels. The original research on weldability established the fact that hardening and the accompanying loss of ductility near the welds are directly related to the cooling rate. Present work is aimed at synthesizing various weld microstructures which are found at different distances from the weld counterline and testing these microstructures.

Following Dr. Nippes talk, a brief question and answer period, conducted by Sidney Low of the Chapman Valve Manufacturing Company, indicated great interest in the subject. About 80 persons attended the meeting.

Dinner speaker was Charles H. Thayer who told how business was conducted in the Connecticut Valley in Revolutionary times.

### *Wichita*

A buffet supper was served at the Cardwell Mfg. Co., Inc. Plant on January 10th. The Wichita Section of A.S.M. was invited to this meeting. A plant visit was made from 7:30 to 8:00 P.M. Following this Anthony K. Pandjiris, President, Pandjiris Weldment Co., St. Louis, Mo., spoke on "The Design and Production of Weldments." Slides were used to illustrate the talk, both of which were very well received. A demonstration of induction hardening was followed by another plant visit from 9:30 to 10:00 P.M. This was another very good meeting and another record attendance of 96. The speaker was interesting, well informed and presented an unusually good approach. Some 45 A.S.M. Section members were present.

### *Worcester*

The January 25th meeting of the Worcester Section, was held at the Tower House. Eighty-five members and guests turned out to hear Charles H. Jennings of the Westinghouse Electric Corp. present a paper on "Planning for Welding." Mr. Jennings declared that in many shops drawings are inadequately marked for welding, so that the welding operator, often times, is the sole judge of the quantity of welding, size of welds and procedure to be used. Good welding is a joint responsibility of engineering and the shop. Those in charge of engineering should have a knowledge of welding, welding terminology and metallurgy so that the proper materials will be selected from the standpoint of weldability as well as strength. The shop is responsible for the qualification of welding operators.

A movie "Trees to Tribune" was shown before the dinner meeting.

### *Western Michigan*

The Western Michigan Section is planning its Annual Welding Conference for Friday, April 22nd.

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# *abstracts of* CURRENT WELDING PATENTS

## *prepared by V. L. Oldham*

***Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.***

2,494,663—Self-Synchronous Cutting Machine—Rosco R. Lobosco, Elizabeth, N. J., assignor to The Linde Air Products Co., a corporation of Ohio.

This patent relates to a tracer-type of a cutting machine wherein a follower tool is provided and where means moves such tool in accordance with movements of the tracer. The follower tool may be disconnected from the tracer and a self-synchronous generator, which normally controls movement thereof, so that the tool can be moved independently of such generator. Another electric motor means is provided for moving the tool when disconnected from the tracer and this last motor is mechanically and electrically connected with the control synchronous generator referred to before.

2,494,718—Method of Electric Arc Welding—Robert P. Palmer, Steubenville, Ohio.

Palmer's welding method includes laying a weld rod along a desired line of weld upon a workpiece with the weld rod being insulated from the workpiece. A weld arc is struck between the weld rod and the workpiece and current is applied to the weld rod at a plurality of spaced points therealong. As the weld arc progresses to each point of current supply, the current supply is stopped at that point and is reapplied to the weld rod at another point spaced appreciably in advance of the weld, with weld current meanwhile being supplied by the other current supply contacts remaining in electrical connection with the weld rod.

2,494,747—Arc Welding System—Lester D. Drugmand, Greenfield, Wis., assignor to Cutler-Hammer, Inc., Milwaukee, Wis., a corporation of Delaware.

This welding system includes an alternating current supply, a capacitor, rectifying means for charging the capacitor and a normally nonconducting electron tube having its main electrodes connected to the capacitor and having a control electrode upon which initiation of the tubes conduction is dependant. Other means supply limited half-cycles of a given polarity of electric energy to the control electrode to initiate discharge of the capacitor through the tube. A translating circuit is provided and energy transmitting means are connected between the current supply source and the translating circuit which is dependant for effectiveness upon discharge of the capacitor.

2,494,847—Safety Control for Welders—Jerome B. Welch, Wauwatosa, Wis., assignor to Cutler-Hammer, Inc., Milwaukee, Wis., a corporation of Delaware.

An electrode carrier having first and second parts with straight-line lost-motion connection therebetween is provided in this patent. An electrode is carried by the first part and movable into and away from the work whereas cooperating contact elements are associated with the carrier for control of the electric supply circuit therefore. Power actuated means are provided to take up the lost motion between the carrier parts to close the contact elements carried thereby and provide electrical energy for the electrodes.

2,494,856—Device for Making Coated Welding Rods—Johannes Bernard Aninga and Jan Tenger, Eindhoven, Netherlands, assignors to Hartford National Bank and Trust Co., Hartford, Conn., as trustee.

This patent covers a specialized apparatus of the character indicated.

2,494,994—Metal Cutting Machine—Gumersindo V. Gamallo, Youngstown, Ohio.

The patented metal-cutting machine includes a bridge member spanning certain metal moving means and frame members that are adjustably positioned on the bridge member. A cutting torch is positioned on each of the frame members and control means are individually provided for the cutting torches. A predetermined spaced relationship is maintained between the torches and the metal to be cut whereas additional means are provided for simultaneously manipulating the control means on each of the cutting torches.

2,495,129—Welding Equipment—Clarence Earl Perrine and Archibald Murray Brown, Akron, Ohio, assignors to The Firestone Tire & Rubber Co., Akron, Ohio, a corporation of Ohio.

Certain gas transfer equipment is provided in this patent and is adapted for use interiorly of a cylindrical and rotatably mounted workpiece whereby a gas inlet element can be positioned within a cylindrical workpiece and provide gas flow to the weld area as a circumferentially directed weld is formed in the workpiece.

2,495,155—High-Frequency Stabilized Arc Welding System—Earl B. Ankenman, Cincinnati, Ohio, assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

The combination of an arc-welding circuit, a high-frequency arc stabilizer and coupling means connected in the arc-welding circuit to couple the stabilizer and the arc-welding circuit, are provided in this patent. Impedance means are connected in shunt relation with the coupling means to provide a path for a portion of the arc-welding current.

2,492,200—Platen Control Mechanism for Welding—Hermann W. Stieglitz, Marblehead, Mass., assignor to Thomson Electric Welder Co., Lynn, Mass., a corporation of Massachusetts.

This patent covers a special control device for the motion of a platen of a flash-butt welding machine.

2,492,551—Resistance Welding—Paul E. Brunberg, Detroit, Michigan.

Brunberg's apparatus relates to an electrode mount for a spot welder and includes a guide means that permits a translatory movement of the electrode. A spring exerts a force on the electrode, a toggle loads the spring in its overcenter position and solenoid means are provided for controlling the position of the electrode.

2,492,572—Tubing Support for Tubing Welders—Rea I. Hahn, Richard W. Spears and Bernard E. Frank, Rochester, N. Y., assignors to General Motors Corp., Detroit, Mich., a corporation of Delaware.

A special fixture for supporting tubing in an electric welder is disclosed in this patent.

2,492,578—Welding Electrode—Harold A. Johnson, Milan, Ill.

Johnson's electrode has means therein for providing cooling fluid for a recess in the rear of a tip that is mounted in one end of the electrode holder.

2,493,143—Weld Rod—Glenn R. Ingels, Houston, Tex.

This patent discloses a method of making an easy flowing weld rod and it comprises depositing a special material upon a binder material. The binder material is forged intimately in between the grains of the other material.

2,493,283—Ferrule for Welding—Charles S. Evans, Atherton, Calif., assignor, by mesne assignments, to Morton Gregory Corp., a corporation of Michigan.

Evans' patented construction encloses the end of a stud as it is being welded to a plate. His ferrule has internal and external recesses extending axially of the device from opposite ends thereof and past a common plane perpendicular to the axis of the ferrule to join a vent formed in the sleeve.

2,493,372—Brazing Flux Composition—Harold R. Williams, Cleveland, Ohio.

This novel flux includes small amounts of zinc chloride, ammonium chloride and cryolithionite and large amounts of diethylene glycol monoethyl ether and braze alloy particles.

2,493,762—Resistance Welding Method Employing Electrical Energy Storage Means—Hans Klemperer, Belmont, Mass., assignor to Raytheon Manufacturing Co., Newton, Mass., a corporation of Delaware.

Klemperer's method comprises storing electrical energy, discharging the stored energy into a resistance welding load, trapping the residual energy of the discharge in the same polarity as the initial charge of stored energy and building up the residual energy to the initial value.

2,493,950—High-Frequency Inductive Welding Apparatus—William G. Dow and Harold C. Early, Boston, Mass., and Henry J. Gomberg, Washington, D. C., assignors to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This high-frequency apparatus has a plurality of conductive power supply means shaped to form concentric portions of a platform for a workpiece. The platform has an opening therein and groups of magnetic and nonmagnetic laminations are positioned in the opening to respectively concentrate the current in and to cool the surface of the work

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# LIST OF NEW MEMBERS

***January 1 to January 31, 1950***

**ATLANTA**

Kelly, L. L. (B)

**BOSTON**

Brooks, James W. (C)
Clark, Joel E. (C)
Sullivan, Robert J. (C)
Udin, Harry (C)

**BRIDGEPORT**

Zinn, Walter J. (C)

**CHATTANOOGA**

Buffington, Harold D. (C)

**CHICAGO**

Chester, W. T. (B)
Feil, Hugh J. (C)
Horton, W. B. (C)
Quinlan, Ralph E. (C)
Risak, Frank A. (C)
Strutz, C. R. (B)

**CINCINNATI**

McVay, Turner (B)

**CLEVELAND**

Strohl, Orval A. (B)

**COLORADO**

Krening, Henry H. (C)
Smith, Fred R. (B)

**COLUMBUS**

Nelson, Jerry (D)
Rock, Stephen Louis (D)

**DALLAS**

Houston, J. B. (C)
Stiles, Aubrey A. (B)

**DAYTON**

Blevins, Paul G. (D)
McVay, Wellesley J. (D)

**DETROIT**

Bowditch, William Aubrey (D)
Courtemanche, E. O. (B)
Diment, Charles H. (C)
Dittmer, Muriel (B)
Doan, P. C. (C)
Goffin, George (B)
Greenwood, Walter, Jr. (B)
Hill, A. R. (C)
Joysey, Thomas (B)
Key, Owen R. (B)
Kirkhof, Russell H. (B)
Macko, Andy (B)
Prange, M. (C)
Reed, Edwin B. (C)
Robinson, Marshall A. (B)
Runson, Frank (B)
Stephens, James F. (B)
Tussy, Don (B)
Zisman, C. H. (B)

**HARTFORD**

Hanelius, Otto A. (C)

**HOUSTON**

Dawson, R. A. J. (B)
Trimble, Edwin Logan (C)

**INLAND EMPIRE**

Wold, Cornell (C)

**LEHIGH VALLEY**

Astleford, Thomas F. (B)
Marvin, Percy E. (C)
Snyder, James Nevin (C)
Topractsoglou, Anastasios A. (D)

**LONG BEACH**

Carlson, Donald A. (C)
Robinson, Herbert B. (C)

**LOS ANGELES**

Boren, William R. (D)
Faringhy, Louis N. (D)
Greve, Elmo M. (D)
Riegel, Robert G. (B)

**MARYLAND**

Jakoby, Edward N. (C)

**MILWAUKEE**

Svacina, John E. (B)

**NEW ORLEANS**

Gardner, Thomas H. (B)

**NEW JERSEY**

Hansen, Carrol (C)
Hila, John (C)
Holton, James T. (C)
Nilssen, Lief (C)
Vogt, Edward (C)
Wilson, William T. (C)

**NEW YORK**

Kelting, C. A. (B)
Moog, George C. (C)
Plants, H. J. (C)

**NIAGARA FRONTIER**

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*Supplement to The Welding Journal, March, 1950*


# Preliminary Results of Welding-Peening Investigation


*A preliminary report on a comprehensive investigation to evaluate each of the many variables involved in peening. New measuring tools and equipment have been developed*



*by J. Lyell Wilson*


## INTRODUCTION

THE application of peening as an adjunct to the welding procedure, in certain circumstances, is not new and is almost as old a practice as that of metal-arc welding itself. The use of peening in this art appears to have evolved in a more or less haphazard manner and to have been credited as a benefit principally because some joints which otherwise could not be completed in one piece were found to be possible of satisfactory completion when peening was introduced as part of the welding procedure for the problem joints. Since the tendency toward cracking during the welding process, especially under conditions of high restraint, was attributed to the effects of shrinkage, loosely referred to as residual stress, and because the use of peening minimized such cracking, the practice of peening was assumed to be beneficial in reducing residual stresses.

While there are instances, as with very heavy weldments having extremely high geometry restraint, where interpass peening did not prevent cracking, the practice of peening in general has been satisfactory in this respect. The theories evolved to explain why such benefits accrue from peening are as diverse as the techniques thereby recommended and even required. Such methods range from the two extremes, that of peening only the external weld passes, and that of peening only the internal passes. Other equally important factors, such as optimum temperature, size (weight) of hammer, size (weight) of tool, shape of tool and relative degree of "riding" the hammer, etc., have been less clearly defined or established than have the general procedures of the peening operations.

Whatever the reason may be for any observed beneficial effect of peening, however, at least one careful investigation disclosed that practically negligible differences in residual stresses resulted from the application of one recognized peening technique compared with that of an unpeened comparable sample.[1]

From these tests the conclusions drawn by the authors are summarized as follows:

1. In butt welds hot peening does not reduce residual stresses unless the last passes are peened.

2. The longitudinal residual stresses of welds may be reduced to less than 25,000 psi. by peening the weld after it has been completed and cooled nearly to ambient temperature. This procedure will not produce appreciable reduction of the transverse compression at the ends of the weld, or reduce the transverse tension in welds under transverse restraint.

3. Peening, to obtain maximum reduction (below 21,000 psi.) of longitudinal residual stresses, to reduce the transverse compression at the ends of welds or to reduce the transverse tension in welds having high-transverse restraint, must be applied to the weld and adjacent plate metal for at least 2 in. on either (both)


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Presented at Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

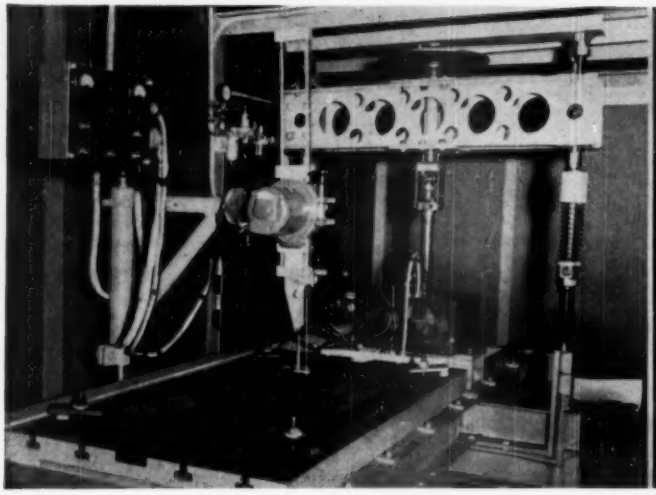

*Fig. 1 Welding peening machine*

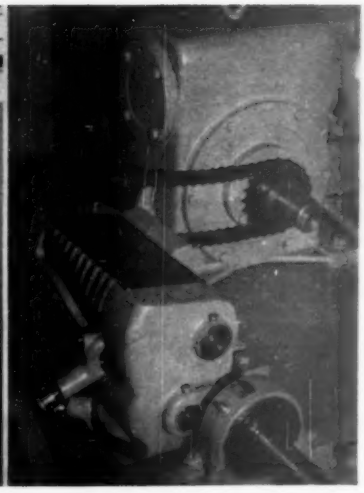

*Fig. 2 Driving mechanism*

side of the weld after it is completed and has cooled nearly to ambient temperature.

4. Deposition of the last passes of a weld after all stresses from previous passes have been eliminated will produce residual stresses of approximately the same magnitude as would have existed had no stress relief taken place on previous passes.

Such findings appear to be seriously contradictory to the theory upon which interpass peening was predicated. However, it should be noted that the implied major premise for this project was that residual stress is the sole criterion for the establishment of final quality. It is therefore a significant observation that the same investigators subsequently reported other findings in residual stress studies on ship plate panels and related structures which formed the principal foundation for the conclusion that residual stress, as such, had very little if anything to do with failures (i.e., were not a major cause for fracture). Under the circumstances it seems advisable to suggest that the peening problem may not be solved through a study of resultant residual stresses alone and that other criteria must be explored for a more complete picture.

In the aforementioned project every effort was made to attain good reproducibility which incidentally poses many difficult problems which have discouraged some investigators from pursuing the problem of peening. Apparently, however, the air pressure was controlled at between 95 to 105 psi. and the several air hammers ranged from 2300 to 5200 blows per minute. These characteristics are apparently manufacturers ratings. The rate of peening (tool travel) and the amount of loading (riding load) were controlled, as well as could be, manually and, since one standardized procedure was developed and used, sufficed for all practical purposes to produce relative values.

Although the results were not published in THE WELDING JOURNAL until about 18 months later, an investigation was being carried out on weld peening at the University of Washington[2] almost concurrently with that previously mentioned at the University of California.

While further effort was made in this second study to develop a holding jig for the hammer for greater control and better reproducibility of peening, the criterion of residual stress (effect in stress relief) is specifically the major premise. Data regarding air pressure, hammer size and frequency of blows are not included but it is assumed that only one size of air hammer was used in this investigation. Some of the answers to the questions indicated as the scope of this second thesis must therefore be assumed to be based on academic reasoning. The conclusions are summarized as follows:

1. Cold peening is purely a surface-working effect. The depth of crystal deformation for a given tool will depend on the impact of the hammer and size and shape of tool. The larger hammer with greater impact

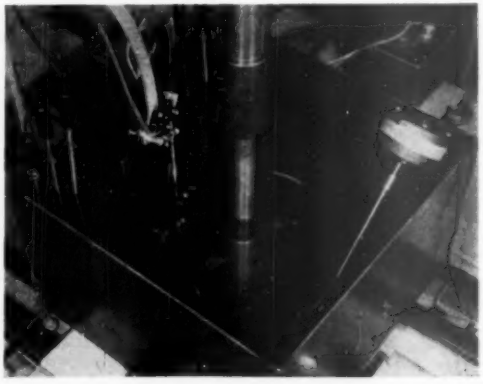

*Fig. 3 Oil bath and jig*

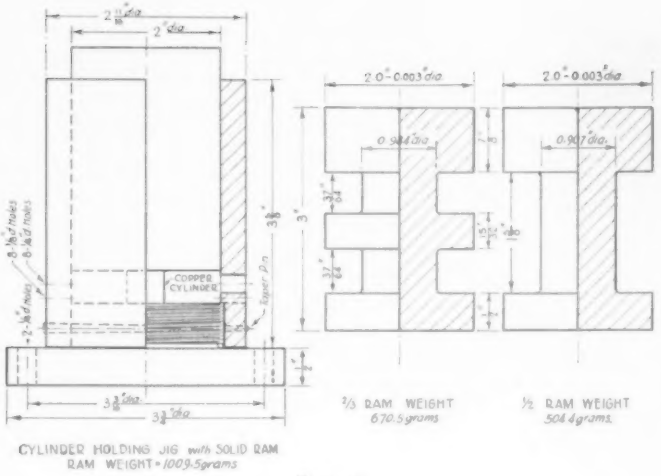


*Figure 4*

strength will produce more depth of indentation and plastic flow. A tool of smaller area in contact with the metal being peened will produce greater depth of plastic flow than one of larger area.

2. For field work using electrode sizes suitable for all-position application (E6010 Classification) peening to the extent of 1.5 min. per square inch of exposed bead area will give plastic flow and full stress relief with tools and hammer described in this paper. (It has been noted that the data regarding hammer and tools are not included in the published discussion.)

3. Flaking may serve as an indication for extent of peening. This condition appears to occur at the point where the weldment no longer responds to peening. No harmful effects from flaking were observed if subsequent passes were applied.

4. No appreciable reduction in ductility was observed. (It is assumed that ductility here refers only to the orthodox characteristic since only standard joint tests are mentioned in the text.)

5. Increasing or decreasing the "hold-on" pressure has no influence on the amount of work accomplished by a hammer, if the shoulder of the tool is, at the beginning of each stroke of the ram, properly engaged by the barrel of the hammer. This requires only a nominal amount of effort from the operator.

6. A small, spherically shaped peening tool will give more rapid crystal deformation than a larger tool which is more nearly flat on the face. It appears that where a very flat tool is used, the peening effect is superficial. A spherically shaped tool of smaller size will be conducive to greater indentation and deeper plastic flow.

Since the foregoing investigations were both based upon the same criterion, residual stress, and as previously stated because residual stress is now considered relatively of minor significance, it appears that the entire problem regarding the relative benefits and deleterious effects, if any, of the peening of welding remains to be solved. Even though we admit that peening appears to be desirable under some circumstances there is very little real evidence as to whether such peening results in effects of such nature as to balance or unbalance benefits and detriments, if both exist after peening. As indicated in the foregoing summary of two outstanding investigations into one phase of the problem there are at present two diametrically opposite conclusions derived from different techniques aimed in the same direction. On the one hand it is demonstrated that no appreciable change in residual stress results from peening except by a specific and unusual method and on the other hand it is stated as a result of comparable study that a generally accepted peening technique "will give plastic flow and full stress relief."

This sort of a situation merely emphasizes the fact that the effects of peening must be explored under conditions which will permit more accurate evaluation of not only those effects which more accurately reflect the most critical characteristics of the welded joint but also of the variable characteristics of the very pneumatic tools which are almost universally used for peening. Accordingly the American Bureau of Shipping proposed to the Welding Research Council that a welding-peening project be sponsored through the appropriate Committee along substantially the following lines.

## Welding Research Council and American Bureau of Shipping—Welding-Peening Project

### OBJECTIVES

At the very outset, the Peening Committee of the Welding Research Council decided that the following possible objectives of the investigation should be considered as the project developed:

1. Furnish scientific data as to the correctness of code requirements relative to the elimination of the peening of the first and last layers.

2. Information as to the variables of peening which might be used by codes as a matter of control.

3. Effect of peening on transition temperature of weld metal and the welded joint as a whole.

Within the scope of these objectives and by using automatically controlled welding and peening operations, it was proposed that the following principal variables should be explored:

(*a*) Size (weight) of hammer.

(*b*) Adjustment (stroke frequency) of air pressure.

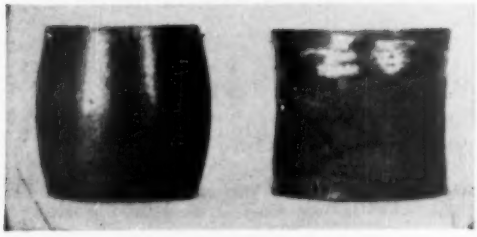

*Fig. 5 Typical cylinders*

(*c*) Temperature (time) at which peening is applied.

(*d*) All variables, (*a*), (*b*) and (*c*) to be explored under two peening conditions, viz:

1. Peening all but first and last or the both outside layers of weld deposits.
2. Peening only the outside layers of weld deposits.

## PROCEDURE

In order to carry out the objectives properly, the project was planned in three major phases, (1) the development of equipment and instrumentation, (2) the calibration and (3) the making and testing of samples. These three phases are outlined as follows:

Phase I

1. Development of mechanical equipment necessary for automatically controlling:
   (*a*) Ambient conditions.
   (*b*) All welding characteristics and operation.
   (*c*) Air pressures and timing.
   (*d*) All thermal conditions of samples being worked.
2. Development of a universal machine for the automatic operation in welding and peening.
3. Development and application of the instrumentation.

Phase II

1. Calibrate pneumatic hammers to establish relative energy levels with the following variables:
   (*a*) Three hammers, light, medium and heavy
   (*b*) Four air pressures, 60, 75, 90 and 105 psi.
   (*c*) Four riding loads, 0, 50, 100 and 150 lb.
2. The first series of calibrations was to be with copper cylinders (pure CCC electrolytic copper), 0.50 in. diameter by 0.425 in. length, which were completely annealed, quenched and pickled before being used. The basis for energy comparisons was to be the stress-strain measurement data of identical cylinders (3) calibrated in a standard tensile machine under compression.
3. For comparative purposes a second set of cylinders from the base or prime plate was to be similarly tested under the hammers.
4. A third set of cylinders from the weld metal was to be similarly tested.

Phases III and IV

When completed results of calibration are available, Phase III will comprise the work of preparing welded samples for peening under the various conditions considered appropriate as determined from a study of the calibration test results. Following these operations, Phase IV will include the cutting, preparation and the testing of the samples to determine transition temperature data and probably some of the following characteristic studies:

(*a*) Tension tests across joint

| HAMMER | LOAD - LBS. | AIR PRESSURES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 45 PSI. | | 60 PSI. | | 75 PSI. | | 90 PSI. | | 105 PSI. | |
| | | NO. | COMP. | NO. | COMP. | NO. | COMP. | NO. | COMP. | NO. | COMP. |
| | | COPPER CYLINDERS 0.425"lengths × 0.50"dias. AT 210° F OIL BATH | | | | | | | | | |
| LIGHT | 0 | 2240 | | 2526 | 0.129 | 2716 | 0.162 | 2856 | 0.183 | 3000 | 0.201 |
| | 50 | 2219 | | 2455 | 0.114 | 2670 | 0.139 | 2785 | 0.190 | 3043 | 0.211 |
| | 100 | 2185 | | 2445 | 0.117 | 2660 | 0.164 | 2804 | 0.193 | 2985 | 0.208 |
| | 150 | 2187 | | 2442 | 0.136 | 2596 | 0.188 | 2797 | 0.202 | 2954 | 0.214 |
| MEDIUM | 0 | 1431 | | 1643 | 0.146 | 1731 | 0.207 | 1816 | 0.235 | 1858 | 0.256 |
| | 50 | 1506 | | 1731 | 0.148 | 1952 | 0.197 | 2096 | 0.225 | 2250 | 0.244 |
| | 100 | 1504 | | 1720 | 0.142 | 1998 | 0.193 | 2190 | 0.222 | 2376 | 0.238 |
| | 150 | 1593 | | 1789 | 0.153 | 1998 | 0.203 | 2211 | 0.220 | 2392 | 0.239 |
| HEAVY | 0 | | | | 0.233 | | 0.253 | | 0.273 | | 0.288 |
| | 50 | | | | 0.233 | | 0.266 | | 0.278 | | 0.284 |
| | 100 | | | | 0.259 | | 0.282 | | 0.317 | | 0.329 |
| | 150 | | | | 0.244 | | 0.275 | | 0.314 | | 0.309 |
| | | COPPER CYLINDERS 0.75"length × 0.75"dia AT 210°F & 70°F OIL BATH | | | | | | | | | |
| MED | 50 | 210° | | | 0.080 | | 0.126 | | 0.173 | | 0.181 |
| | 50 | 70° | | | 0.086 | | 0.124 | | 0.154 | | 0.187 |
| | | COPPER CYLINDERS 0.425"length × 0.50"dia AT 70° F OIL BATH | | | | | | | | | |
| L | 150 | | | | | | | | 0.206 | | |
| M | 0 | | | | 0.130 | | 0.196 | | 0.229 | | 0.233 |
| H | 100 | | | | | | | | 0.262 | | |
| | | PLATE & WELD METAL CYLINDERS 0.5" × 0.5" ALL AT 90 PSI. | | | | | | | | | |
| | | MAT | TEMP. | WITH AS-ROLLED PLATE | | | | WITH NORM. PLATE | | | |
| L | 150 | WELD | 70° | VERT. | 0.010 | LONG. | 0.003 | VERT. | 0.003 | LONG. | 0.005 |
| M | 0 | WELD | 70° | VERT. | 0.046 | LONG. | 0.046 | VERT. | 0.042 | LONG. | 0.047 |
| H | 100 | WELD | 70° | VERT | 0.096 | LONG | 0.090 | VERT | 0.078 | LONG. | 0.140? |
| 210° | 90 PSI | WELD | L-150* | L-.015 | V-.011 | M-0* | L-.045 | V-.045 | H-100* | L.082 | V.074 |
| L | 150 | PLATE | 70° | | | LONG. | 0.030 | | | LONG. | 0.036 |
| H | 100 | PLATE | 70° | | | LONG. | 0.126 | | | LONG. | 0.110 |
| | | MAT. | TEMP. | WITH AS-ROLLED PLATE | | | | WITH NORM. PLATE | | | |
| M | 0 | PLATE | 210° | L-0.081 | | T-0.087 | V-0.097 | L-0.090 | | T-0.079 | V-0.101 |
| M | 0 | PLATE | 70° | L-0.083 | | T-0.077 | V-0.084 | L-0.083 | | T-0.086 | V-0.077 |

*Fig. 6 Summary of data—averages of observed calibration values*

(*b*) Tension tests of all-weld metal
(*c*) Guided bends
(*d*) Tukon hardness surveys
(*e*) Macro and micro studies

However, the purpose of the present paper is to describe the work carried out under Phases I and II and, in presenting the data derived from the calibration work of Phase II, indicate the factors which appear to

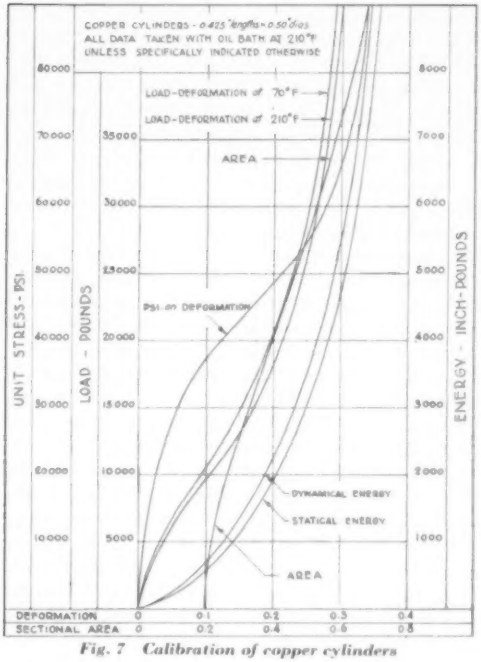


*Fig. 7 Calibration of copper cylinders*

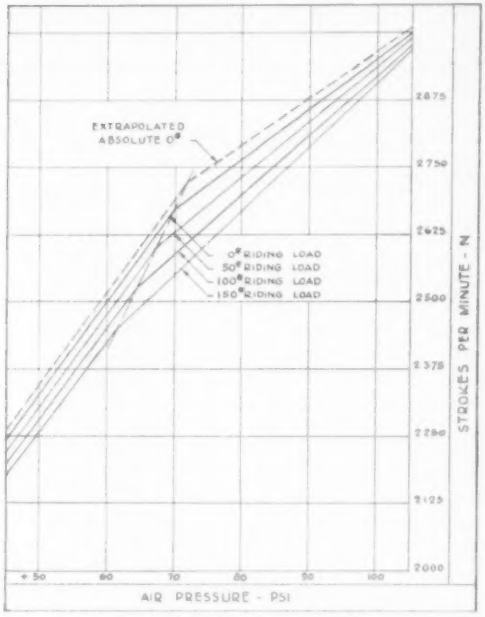


*Fig. 9 Light hammer calibration*

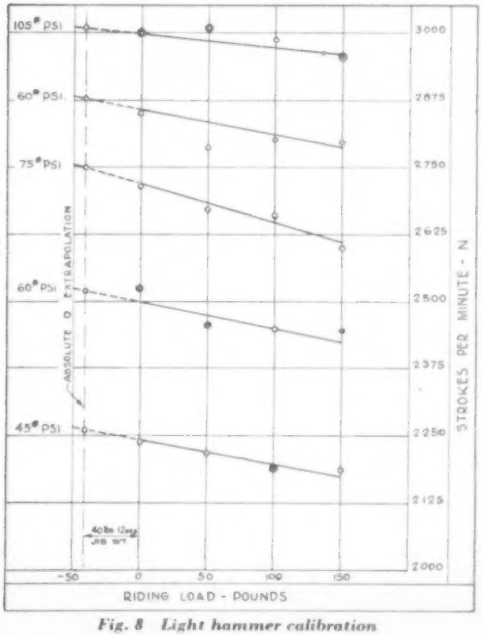


*Fig. 8 Light hammer calibration*

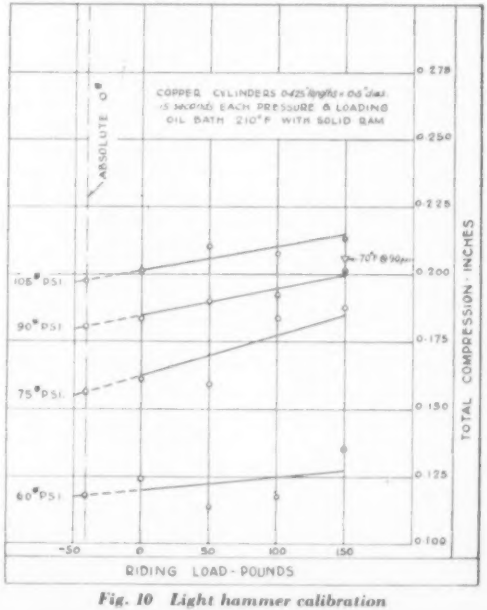


*Fig. 10 Light hammer calibration*

contradict some previous findings and certainly to differ from certain preconceived ideas regarding the characteristics of pneumatic tool performance. The results thus far obtained seem to indicate that the careful approach to the establishment of fundamental factors as recommended by the Peening Committee is fully justified and what is more important that the application of peening to the welded joints should be fully explored perhaps even beyond the scope which has been blueprinted.

## WELDING-PEENING EQUIPMENT

The development of mechanical equipment and of automatic controls was of necessity one over-all problem and was carried out as such. It included the construction of a special soundproofed room, thermally insulated, within the laboratory. This double-walled room, completely air conditioned, is sufficiently large to contain the operating machine with all necessary operating and control adjustment switch gear and valves while the compressor, control panel boxes, welding machine and similar equipment were located conveniently outside the special room.

In order to provide generous inertia, the welding-peening machine, intended to perform all welding and peening automatically, was constructed of relatively heavy members, as illustrated in Fig. 1. As completed, therefore, its total weight is approximately between $2^1/_2$ and 3 tons, the moving stage alone being 3000 lbs. This machine consists essentially of two heavy 8-in. wide flanged I-beams, 15 ft. long, on each of which is mounted and secured a miniature steel rail, accurately aligned and on which the heavy cast-iron stage rides very much as a planer.

This stage, slotted for securing the work samples, rides on six solid-steel roller wheels machined to fit the rail heads and its travel is actuated by a lead screw driven at the desired speed by means of a ratiomotor and screw-cutting gear box. With such change gears and drive mechanism, shown in Fig. 2, the speed of travel can be adjusted accurately to values within a range of from about $^1/_2$ to 24 in. per minute with not more than one sprocket change. The range of travel on the lead screw is about 11 ft. and since the stage is 5 ft. long the rails are fitted with mechanical stops in addition to limit switches.

By mounting the main 8-in. beams on top of three cross members of the same section, which in turn were each mounted on two spring-box vibration dampeners there is practically no vibration transmitted to the concrete floor. The most important result, however, is that the entire machine comprises a heavy mass with ample solidity as a foundation and yet one having no rigid attachments to anything outside of itself, even to the floor—it really floats on dampeners.

Uprights are attached to the machine by way of independent cross members hung to the main beams between those carrying the load to the floor mountings. As shown in Fig. 1, the cantilever support carries the adjustable bracket for the automatic welding head while the symmetrical pair of uprights act as guides to the floating cross box beam in the center of which the air hammer holding jig floats as a piston in a cylinder. The

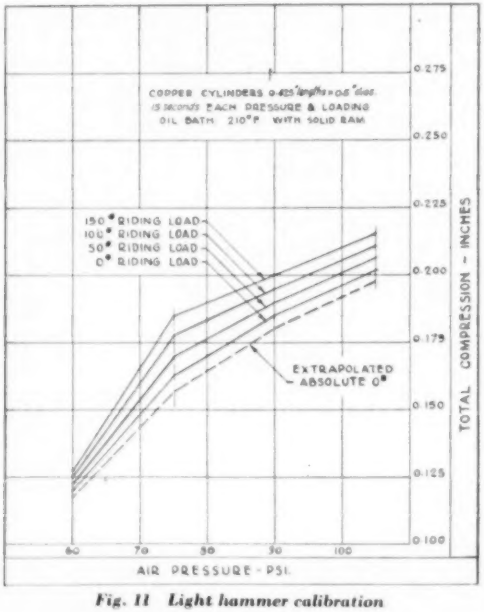


*Fig. 11 Light hammer calibration*

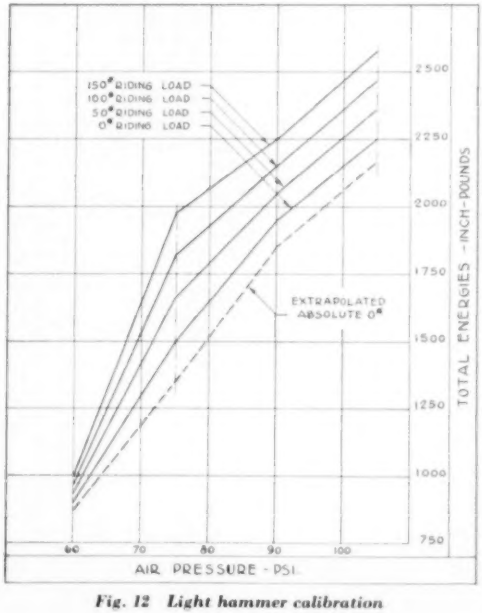


*Fig. 12 Light hammer calibration*

uprights are located 5 ft. apart and are each 5 ft. from the ends of the machine.

Each of the three air hammers is fitted with its own special clamp type yoke for attachment to the holding jig in such a manner as to permit the normal positions of the tool points to impinge at a common level when at rest. Two auxiliary slide rods are fitted on opposite sides of the holding jig's main stem acting as slide keys to keep the jig and hence the hammers from turning. Similarly each hammer is provided with a retainer for the tool and the tool blanks are specially socketed in square, hexagonal, etc., shapes to prevent turning.

The three air hammers with tool blanks and accessories, together with the electrically driven air compressor, storage tank and control equipment, have been furnished for use on the project through the generous cooperation of the Chicago Pneumatic Tool Co., and their assistance in this respect has been most valuable.

The compressor has a 10-hp. motor drive and just enough over capacity and air storage to keep the heavy hammer operating continuously. In order to minimize the noise in the laboratory the compressor equipment is located in the machinery room of the building and the air supply line is carried to a manifold in the project room. Included within this room at the manifold are the reducing valve, control valves, filters and gages together with the solenoid control valve used for actual operation, the hand throttle on each hammer being clamped in the fully open position.

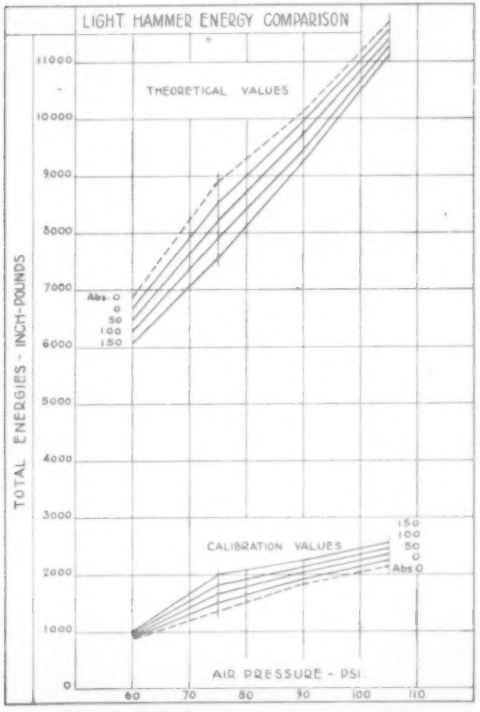


*Fig. 13 Light hammer energy comparison*

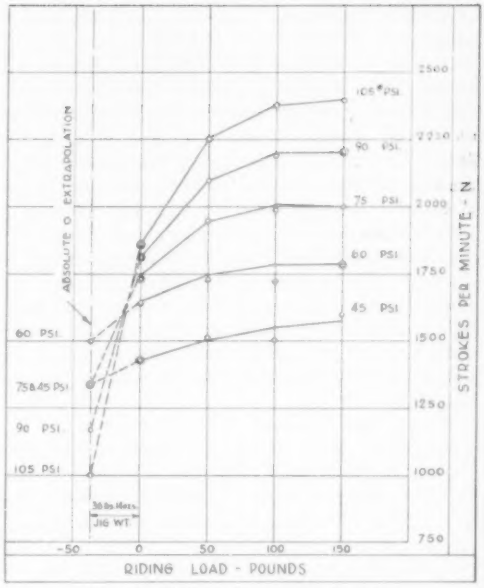


*Fig. 14 Medium hammer calibration*

Operation is controlled through the solenoid valve by way of an electrical timing switch so that the actual operation of the hammer may be timed accurately in seconds and with the most important feature of absolute reproducibility on timing. In order to minimize "over-riding" or coasting after the main solenoid stop valve closes, the rubber hose pendant to the hammer handle is as short as possible, the solenoid valve being mounted on the flange of the cross box beam near the hammer for this reason.

## HAMMER STROKE FREQUENCY CALIBRATION

In order to determine the number of blows per minute for each of the three hammers, experiments were made with several different forms of pickups for registration on the oscilloscope. Interferences, in the form of outside pickups, were so troublesome with all of the induction coil arrangements that these were abandoned in favor of the electric-resistance-wire strain gages on the tool. By using two of these strain gages axially on opposite sides of the tool blank, clear well-defined blips could readily be seen on the oscilloscope screen. The dynamical type, high-resistance gages also permitted the application of impulses directly to the oscilloscope and simplified the hookup.

While the preliminary experimental phase of this particular calibration was very troublesome there were no problems with the strain gages in this application more unusual than the all too frequent fractures in the pigtail connections. However, there still remains a question, of not too great significance, with respect to just what the number indicated by the blip frequency

on the scope screen really means. Naturally this was assumed to be the number of blows per minute, but because of the tremendous differences between the corresponding theoretical values of energy and those actually measured by calibration it seems more reasonable for the present to refer to these as the number of strokes per minute pending further review of these and the theoretical analysis. Since they must be multiples of blows per minute, whatever they are called, these numbers are listed in the tabular form of summary, Fig. 6, as numbers and are used in subsequent calculations as stroke frequency. However, as these values enter into calculations only for the theoretical energy output of the hammers their amount is of minor significance and effects only the relative efficiency of the hammer and the accessories used for applying the impact load.

Even a cursory review of the data shown in Fig. 6 will suffice to show that both air pressure and riding load have a considerable effect upon stroke frequency for all hammers and that this variation increases with hammer size. Considerations of this characteristic will be discussed subsequently, however, and for the present it should be noted that, contrary to assumptions previously held, the stroke frequency is definitely not constant and may be considerably less than commercial ratings when measured under actual working conditions carefully controlled.

In calibrating the hammers for stroke frequency, a substantial, heavy plate, box-girder type of anvil was fitted across and locked to the rails directly under the air hammers. The same anvil support also served a similar purpose in calibrating the hammers for energy output except that a tank for the oil bath was added as shown in Fig. 3. This oil bath tank was equipped with heating elements and circulating mechanism together with a cylindrical holding jig and plug piston type rams for holding the copper cylinders as illustrated by Fig. 4. The use of this latter equipment is described in the following discussion.

## STATICAL ENERGY CALIBRATION WITH COPPER CYLINDERS

Using copper cylinders as "compression plugs" in ordinary static press calibration applications is not unusual but similar applications in the dynamical field have been somewhat limited to balistical studies or work of a similar nature where rather high-strain rates are involved. Since the purpose for the statical energy data in this project was to arrive at a proper base line on dynamical energy, existing data on such a relationship between statical and dynamical values was of paramount importance. Accordingly the information and references made available through physicists in both Navy and Army experimental work of this nature was of considerable value in the preliminary studies for this phase of the calibration work. While the work was not necessarily shortened thereby, it helped considerably to have comparable results not merely as check data but for the important relationship between "one-shot" impacts as compared with repeated cycles of much smaller impact loads of uniform value.

There were also minor problems in the initial stages of the statical calibration in the testing machine where much trouble resulted from the dimensional propor-

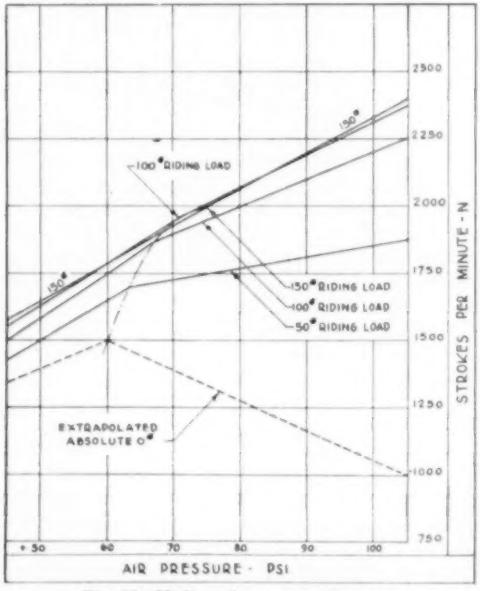


*Fig. 15 Medium hammer calibration*

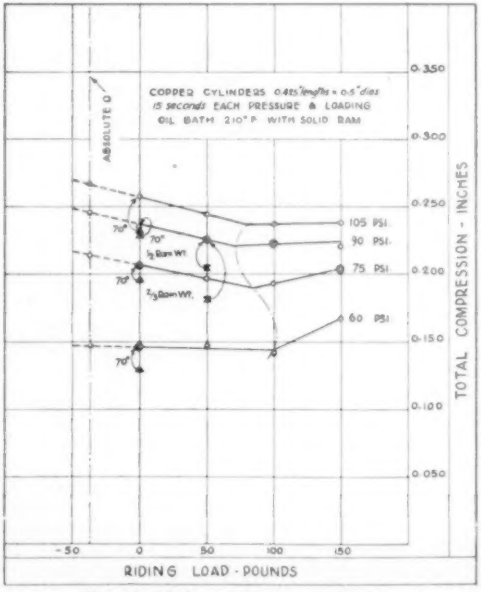


*Fig. 16 Medium hammer calibration*

tions of the copper cylinders. Careful checking confirmed the fact that the quality and grade of copper, the annealing, quenching, pickling and temperature control during compression, were satisfactory but the results were not. The characteristic curves derived from stress-strain data seemed appropriate and comparable with previous findings but the "Tower of Pisa" look of the cylinders after compression indicated a possible slip discrepancy on final deformation. Finally, by changing the length of the cylinders to about half the former amount (1.00 to 0.425 in.), thereby conforming more closely to proportions used in other investigations, the ultimate results were quite normal in both appearance and as technical data.

Copper cylinders were machined from pure electrolytic copper (CCC grade) to a final length of 0.425 $\pm$ 0.0005 in. and to a diameter of 0.50 $\pm$ 0.0005 in. All of the copper bar stock was furnished by the American Brass Co. through the courtesy of John R. Freeman, Jr., Technical Manager, and it is of stock commercially known as hard-drawn electrolytic tough pitch copper rod. To insure proper bearing surfaces the ends of the cylinders were ground parallel in a special jig to the final dimensions. All copper cylinders were annealed in an electrically heated furnace at a temperature of 1150° F. The temperature was maintained for 1 hr. and the cylinders were then quenched in water at 100° F. and finally pickled.

An oil bath was provided during testing to hold the temperature of the copper to a minimum of 200° F. in order to avoid as much work hardening as possible. A light gage mild-steel square container having a heavy bottom plate was used for the oil bath. This was fitted with a hardened steel block in the bottom center and the block contained a ground, slightly oversize, center depression to keep the copper cylinders from slipping out of an approximately central position. The same oil bath container, as previously mentioned and as shown in Fig. 3, was also used for the dynamical calibration under the hammers. It will be seen that this container is also fitted with an electrical thermostat control in the heater circuit and an agitator.

After the load-deformation data, shown in Fig. 7, were carefully checked several times with different cylinders, with practically identical results, the statical calibration was considered satisfactory and, through comparison with comparable independent data, it was felt that the procedure must also be correct up to this point. The equipment was therefore set up under the hammer station in a similar manner for the dynamical work.

## DYNAMICAL ENERGY CALIBRATION WITH COPPER CYLINDERS

The same procedure was then followed with copper cylinders under the hammers except that it became necessary under dynamical conditions to prevent the displacement of the cylinders which otherwise became distorted and useless. The tool of an air hammer is perhaps the most difficult thing to control in precision work and it was considered impossible to confine the tool as by guides because of the uncertain friction thereby introduced. Accordingly, within the oil bath a cylindrical holding jig, illustrated in Fig. 4, was developed with several different weights of piston-like rams. This latter feature was introduced in an effort to detect any effect from the ram mass between the tool

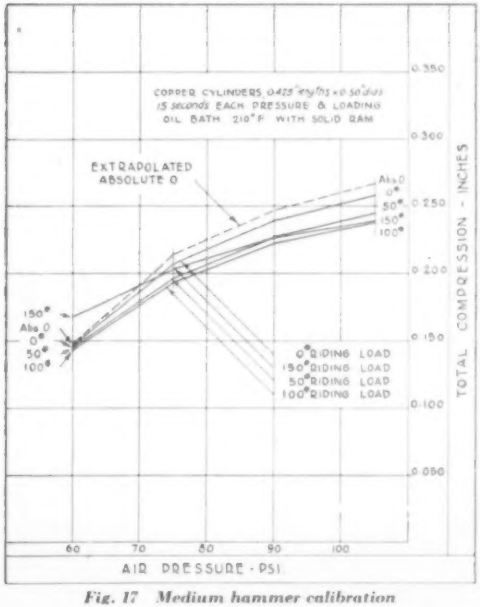


*Fig. 17 Medium hammer calibration*

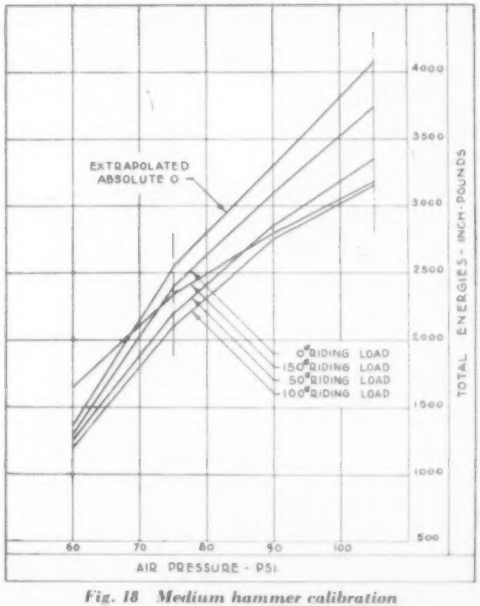


*Fig. 18 Medium hammer calibration*

and the copper. The cylindrical shell was relieved by holes drilled in the sides at the bottom to allow for free flowing of the oil. By means of this holding arrangement it was possible to compress the cylinders (copper) quite readily without any appreciable (measureable) distortion or marking by impact of the cylinder ends so that it was comparatively easy to make accurate micrometer measurements. An enlarged photograph, Fig. 5, illustrates the two typical extremes of resulting shapes. A brief discussion of these contrasting results, which are of no serious significance, is included in reference 3 of the bibliography.

All parts of the cylindrical holding jig were hardened after machining and ground for accuracy. The hardness values aimed for were the same as those found for the tool blanks. Check hardness readings for the copper indicate that practically all work hardening occurs at the first pressure or stroke, is nearly all surface effect and is comparable in both statical and dynamical conditions. However, the most important check on the results obtained is that furnished by comparison with other data from the most reliable sources.

Outstanding among available data seems to be that by E. T. Habib, Physicist, David Taylor Model Basin, Navy Dept., Washington, D. C.,[3] and the one major difference between that work and the peening project is that the impact in the former is furnished by one single blow while in the peening it is by a large number of repeated blows. Since the data check very well indeed it appears reasonable to conclude that within the range of values explored there is no appreciable difference in total energy effect as between comparable energies delivered by single blows and by uniform repeated blows.

The relationship between statical and dynamical energy values, as shown in Fig. 7, corresponds to that derived from Habib's work at the appropriate strain rate which in the case of the air hammers averages not more than the lowest values used in the ballistic studies. In an over-all sense this ratio of dynamical to statical energy averages about 1.175 and appears to be fairly constant within the range of values pertinent to the peening study.

## RESUME OF DATA

I. Hammers—Chicago Pneumatic Tool Co.

(*a*) Yoke, same for all hammers, 21 lb. 2 oz. weight

(*b*) No. 1, heavy, mfrs. designation, No. 60 large hammer

Weights:

| | |
|---|---|
| No. 1 hammer (including piston) | 26 lb. 2½ oz. |
| Holder clamp | 12 lb. 6½ oz. |
| Tool blank | 6 lb. 2½ oz. |
| Piston (274.2 gm.) | 0.604 lb. |

Dimensions of piston and stroke:

| | |
|---|---|
| Piston length | 2.5075 in. |
| Piston diameter | 1.061 in. |
| Piston stroke | 6.00 in. |
| Manufacturer's BPM* | 1340 at 90 psi. |

(*c*) No. 2, medium, mfrs. designation, CP 411

Weights:

| | |
|---|---|
| No. 2 hammer (including piston) | 18 lb. 0 oz. |
| Holder clamp | 15 lb. 12 oz. |
| Tool blank | 1 lb. 13 oz. |
| Piston (stepped—446.9 gm.) | 0.985 lb. |

* Blows per minute.

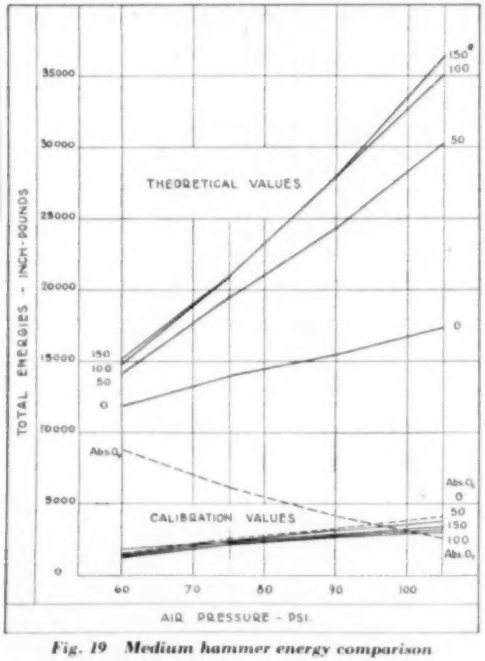


*Fig. 19 Medium hammer energy comparison*

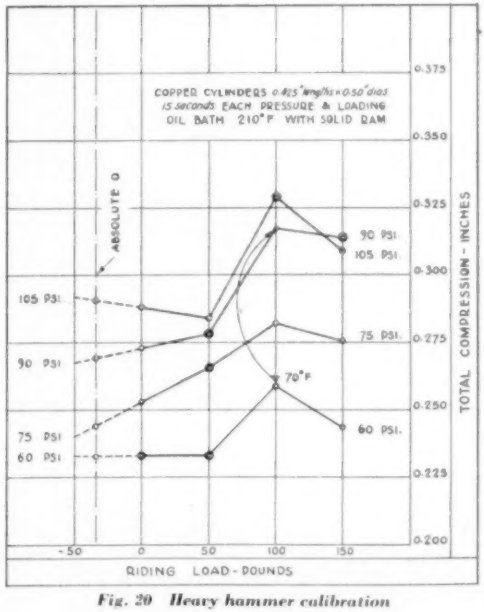


*Fig. 20 Heavy hammer calibration*

Dimensions of piston and stroke:

| | |
|---|---|
| Piston length | 5.625 in. |
| Piston diameter | 1.124 and 0.810 in. |
| Piston stroke | 1.25 in. |
| Manufacturer's BPM | 3150 at 90 psi. |

(*d*) No. 3, light, mfrs. designation, No. 1 chipping hammer

Weights:

| | |
|---|---|
| No. 3 hammer (including piston) | 13 lb. 14 1/2 oz. |
| Holding clamp | 19 lb. 10 oz. |
| Tool blank | 2 lb. 3 oz. |
| Piston (226.4 gm.) | 0.496 lb. |

Dimensions of piston and stroke:

| | |
|---|---|
| Piston length | 1.979 in. |
| Piston diameter | 1.123 in. |
| Piston stroke | 2.250 in. |
| Manufacturer's BPM | 3050 at 90 psi. |

II. Oil Bath Cylindrical Holder and Rams, see Fig. 4.

III. Theoretical Energy Analysis.[4]

$$E \text{ per stroke} = \frac{\overset{\#}{W}p}{2g}\left(\frac{S' \times \text{BPM}}{185}\right)^2 \times 12 \text{ in in.-lb.}$$

$$E \text{ per 15 sec.} = \frac{\overset{\#}{W}p}{2g}\left(\frac{S' \times \text{BPM}}{185}\right)^2 \times 12 \times \frac{\text{BPM}}{4} \text{ in in.-lb.}$$

$$= \text{for No. 1 heavy hammer } \frac{\text{BPM}^3}{33{,}750} \text{ in.-lb.}$$

$$= \text{for No. 2 medium hammer } \frac{\text{BPM}^3}{475{,}000} \text{ in.-lb.}$$

$$= \text{for No. 3 light hammer } \frac{\text{BPM}^3}{293{,}000} \text{ in.-lb.}$$

IV. Stroke Frequency of Hammers, see columns indicated as "No." in the tabular Summary of Data, Fig. 6.

(*a*) The values of stroke frequency ($N$) are plotted and cross-faired as follows:

1. Light hammer No. 3.
   $N$ plotted on riding load, Fig. 8.
   $N$ plotted on air pressure, Fig. 9.
2. Medium hammer No. 2.
   $N$ plotted on riding load, Fig. 14.

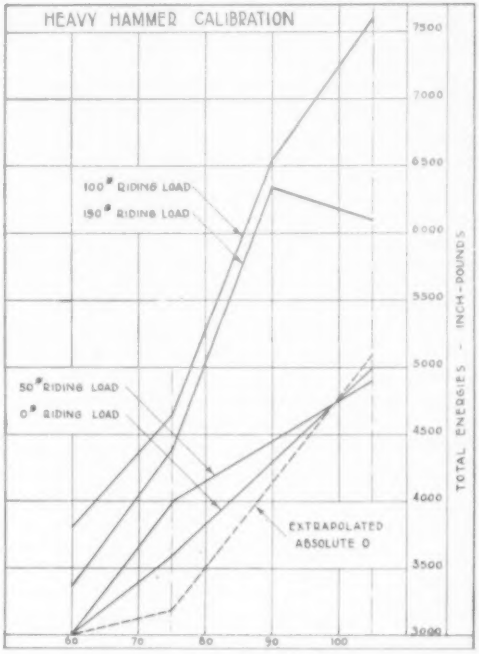


*Fig. 22 Heavy hammer calibration*

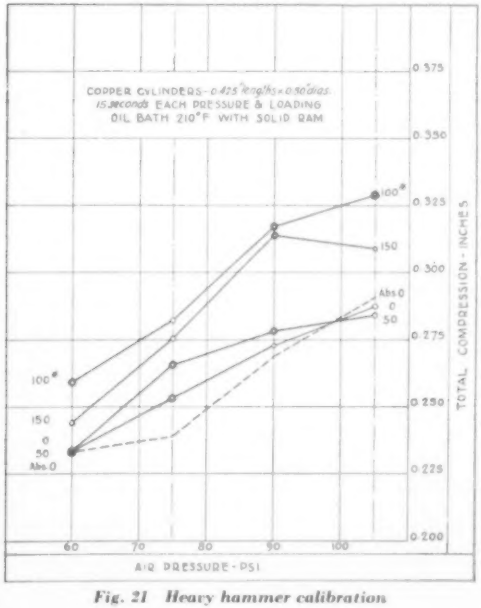
COPPER CYLINDERS - 0.425" lengths x 0.50" dias.
15 seconds EACH PRESSURE & LOADING
OIL BATH 210°F WITH SOLID RAM
TOTAL COMPRESSION - INCHES
AIR PRESSURE - PSI

*Fig. 21 Heavy hammer calibration*

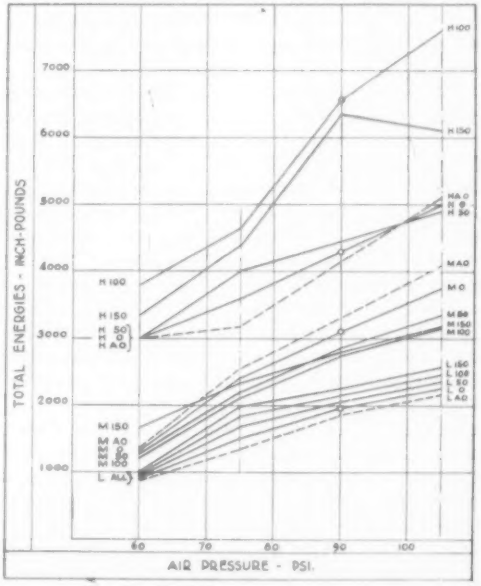


*Fig. 23 Complete energy comparison*

*N* plotted on air pressure, Fig. 15.

3. Heavy hammer No. 1, not yet available but may be added as supplementary data.

V. Compression Values for Copper Cylinders (15 sec.), see columns indicated as "comp." total compression in inches in the tabular Summary of Data, Fig. 6.

(*a*) The values of total compression are similarly plotted and cross-faired as follows:

1. Light hammer No. 3.
   Total compression on riding load, Fig. 10.
   Total compression on air pressure, Fig. 11.
2. Medium hammer No. 2.
   Total compression on riding load, Fig. 16.
   Total compression on air pressure, Fig. 17.
3. Heavy hammer No. 1.
   Total compression on riding load, Fig. 20.
   Total compression on air pressure, Fig. 21.

VI. Total Energies from 15 Sec. Hammer Operation.

(*a*) Converted from dynamical energy curve shown in fundamental data, Fig. 7

(*b*) The values of total energy are plotted for each hammer as follows:

1. Light hammer No. 3, Fig. 12.
2. Medium hammer No. 2, Fig. 18.
3. Heavy hammer No. 1, Fig. 22.

VII. Complete Energy Comparison for all three hammers under all conditions of loading and air pressures are shown in Fig. 23.

## SUMMARY OF FINDINGS

As previously intimated the data for the several hammers used in this project demonstrate the fact that "riding load" has a marked effect upon the hammer performance characteristics. In certain conditions "riding load" has an effect comparable with that resulting from varying air pressure. Generally, however, air pressure is the major factor in hammer performance and the accurate control of air pressure is an important essential for all such studies.

The relationship between the masses of hammer, piston and riding load is significant as a factor. For the present it is assumed that apparent reversals of effect between hammers may therefore be found related through characteristics dependent upon synchronous or natural frequencies of the hammer systems, i.e., masses of hammer, piston and riding load. The mass of the ram in the cylindrical holding jig seems not to be significant.

From observation the body of the hammer seems to work as well as the piston the impact being received at the shoulder on the tool blank. All previous statements contradict this observation, however, and it should be observed that theoretical energies are far in excess of actual values. However infinitesimal such blows from the hammer body may be, it is this possibility that leads to the assumption that stroke frequency is a multiple of the oscilloscope screen indications rather than a direct reading. The point is of minor significance, however, because of the fact that hammer performance efficiency is not being studied since it does not yet seem to be a factor.

The primary purpose of this phase of the project was to verify the effects of riding load and air pressure as applied to the several hammers of known characteristics, and finally to establish by calibration an appropriate energy baseline for the hammers and thus have fairly accurate pilot conditions for peening the welded joint. For the present therefore, it appears that such values have been established rather clearly and the choice might appropriately be those suggested by the circled points on the 90 psi. ordinate and the corresponding curves of the Complete Energy Comparison shown in Fig. 23. In other words, if all three hammers are used at 90 psi. and with 0 riding load (no weight added) the respective total energies for 15 secs. of operation would be:

Light hammer, in.-lbs. ..... 1950
Medium hammer, in.-lbs. ..... 3100
Heavy hammer, in.-lbs. ..... 4300

A further check value for the fourth set would be with the heavy hammer at 90 psi. and 100 lbs. riding load with a 15 secs. energy total of 6567 in.-lbs.

## APPRECIATION

It is possible to express grateful appreciation only in group fashion to so numerous a group of friends and associates who have generously helped in this effort with advice and counsel. At the same time it is felt that the infinite patience and helpful collaboration should be specifically acknowledged to the author's colleagues on the laboratory staff of the American Bureau of Shipping, also the helpful cooperation of the Bureau's executive staff and the painstaking and continuous interest and helpful consideration of members of the Peening Committee of the Welding Research Council, Leon C. Bibber, Chairman, William Bunn, Clarence E. Jackson, Dr. Robert D. Stout and, especially, William Spraragen.

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# Direct Explosion of Welded Joints

***A new technique for determining triaxial sensitivity of steel plates and weldments is described. Some combinations of electrodes and low-alloy steels give better results than others***

*by G. S. Mikhalapov*

## INTRODUCTION

INVESTIGATIONS of the causes of failure of welded-steel merchant vessels constructed during the last war revealed the importance of a property of materials which, though known for many years, had not been hitherto fully appreciated in structural design. This property, known by a somewhat ambiguous term of "notch sensitivity," denotes the ability of material to absorb energy and carry loads in the presence of notches and other geometries producing steep stress gradients. The mechanisms of failure of structures made of notch-sensitive materials is not well understood. However, in practice such structures appear to be unable to undergo plastic flow at points of high-stress concentration and tend to fracture at such points whenever the local stress exceeds the yield strength of material. Furthermore, such local brittle fracture will progress (usually at a very high rate of travel) until the physical continuity of the notch-sensitive material is interrupted or until the fracture reaches an area of zero or compressive stress. Thus it is possible for a structure made of notch-sensitive material to fail at a low average working stress, provided it contains notches or other points of high-stress concentration.

Since notch-sensitive materials may possess excellent ductility and energy absorption properties when stressed uniformly, as for instance in a standard 0.505 tensile-test specimen, a plausible explanation of notch sensitivity is that it is caused by inability of the material to undergo plastic strain in a triaxial stress field.

At present most of our knowledge of the strength of materials is based on their performance under uniaxial loading. However, such limited knowledge as we possess of structural performance of certain materials under biaxial loading fails to show any startling difference in the behavior of materials under biaxial and uniaxial stresses. Accordingly, the theory that the triaxial and uniaxial ductility differ greatly for some materials but not for others is by no means generally accepted. Nevertheless, considerable indirect evidence exists to support the hypothesis that notch-sensitive materials are materials which lose their ability to flow plastically in the presence of a relatively small third-dimensional tension. Thus, whereas both notch-sensitive and notch-tough materials may have equally good plastic ductility under a 1:1:0 ratio stress system, and both obviously will have zero plastic ductility under a 1:1:1 system, the ductility of the notch-sensitive material will decrease at a much faster rate than that of the notch-tough material as the stress system ratio changes from 1:1:0 to 1:1:1.

It is well known that the uniaxial ductility of certain materials, for instance, steel decreases with temperature. The decrease, however, is gradual. Notch sensitivity on the other hand, manifests itself quite abruptly at a specific temperature which varies quite widely for different steels. Practically all ferrous materials are tough at elevated temperatures, and a few remain tough at the temperature of liquid air. However, the majority change from notch tough to notch sensitive at some intermediate temperature.

Since all structures are designed, theoretically at least, well within the yield strength of material used the properties of the material beyond the yield strength are generally considered by the designer to be of importance only at times of excessively high overloads when high plastic ductility provides an additional factor of safety. Unfortunately, strong indications exist that in most structures imperfection of design or workmanship or both produces points of high-stress concentration where plastic strain must take place before full working stress can be developed in the structure as a whole. Once this premise is accepted notch sensitivity or poor triaxial ductility becomes of paramount importance in structural design.

Notch sensitivity of homogeneous materials is usually measured and expressed in terms of a Charpy or an Izod impact test. Useful as these tests are they both have a number of shortcomings. Primarily they are laboratory tests and require exact and careful preparation of specimens or very high scatter will result. They meas-

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ure notch sensitivity of a very small volume of material, that is of the material at the root or base of the notch. If the material is at all nonuniform the test must be repeated with the notch located in several planes and in several portions of the plate or shape tested. Above all, neither one produces a sufficiently severe stress condition, and as a result practically all present structural metals, especially steels, will give relatively high energy absorption values and an apparently ductile fracture when subjected to either Charpy or Izod tests at room temperatures. In other words, the test is not discriminatory enough at room temperature to separate the tough and brittle steels. Accordingly, the test is usually conducted on a series of identical specimens at progressively lower and lower temperatures until the energy absorption drops sharply and the fracture assumes the typical cleavage pattern usually associated with brittle behavior. The temperature at which this occurs is known as the transition temperature of the material and serves as a criterion of its toughness. Unfortunately, most common structural steels have sufficiently low transition temperatures to lead the designers to consider all steels as notch tough for most services.

Experimental research following the failures of welded merchant ships has definitely established that the transition temperature or the temperature at which a steel becomes notch sensitive is a function of a number of factors.[1] These factors, e.g., sharpness of the notch, thickness of the plate, size and geometry of the parts forming the notch or adjacent to the notch, all have one thing in common, they all tend to inhibit the flow of the metal in the plane normal to the lines of major stress in the specimen. Or, if the theory of low triaxial ductility is accepted, they all tend to increase the tension normal to the major stress. Accordingly, it is entirely possible for some steels to be notch sensitive at relatively high temperatures. Thus it was found that the stress system in the corner of the hatch opening in the deck of an early version of the Liberty ship was sufficiently severe to produce brittle failures in most types of steel at room temperature.

The realization of the importance of the notch sensitivity of steels has caused many attempts to develop an improved method of testing for notch sensitivity. Several new tests, such as Kahn's Tear Test, have been developed and some of them overcome to a considerable extent the disadvantages of the Charpy or Izod impact test. All of these tests, however, rely on a mechanical notch to produce a system of stresses necessary to measure notch sensitivity, and all of them, therefore, suffer the common shortcoming of measuring notch sensitivity of a very small volume of the material being tested, and are thus unsatisfactory for nonhomogeneous materials.

The inadequacy of all tests relying on mechanical notches is particularly manifest in the case of structural joints, either mechanical or welded. Although attempts have been made to test over-all performance of welded joints by cutting different notches in various portions of the joint, such tests suffer by their inability to compare directly with tests made on prime plate and by the uncertainty that the stress system produced by the notch is imposed on the weakest, and therefore the critical, portion of the weld.

It has been known for a long time that good correlation exists between notch sensitivity, as revealed by the Charpy or Izod test, and ballistic shock resistance of materials, only the materials with low transition temperatures being able to withstand the shock produced by a glancing blow of a ballistic projectile without shattering into many pieces in a brittle manner. If the theory of low triaxial ductility is accepted as the explanation of notch sensitivity, the reason for this correlation is readily revealed by an analysis of a stress system produced by ballistic impact. Any blow applied against a plate and normal to its surface in a manner to produce bending in the plate and at a velocity sufficiently high to produce a stress shock wave under the area of impact will produce a state of triaxial stress. An exact quantitative analysis of the stress system is quite difficult and involved but its major features are reasonably clear and certain. Assuming that the plate is supported at a uniform distance from the center of impact, the principal stresses will consist of biaxial tension of 1:1 ratio in the plane of the surface of the plate and alternate compression and tension in the plane of the thickness of the plate as the shock wave travels from the impacted side to the opposite side and is reflected back. The magnitude of the former will be the function of the total energy of the blow, while the magnitude of the stress in the plane of the thickness will be a function of the velocity of the impact.[2]

A very good proof of the existence of the tensile stress in the plane of the thickness and its dependence on the velocity of impact is given by the phenomenon of "spalling." While a low velocity impact merely produces a local depression or a bulge in the plate, a high velocity impact will knock out a spall or a plug roughly equal in volume to the area of impact times half the thickness of the plate, from the back of the plate. By properly adjusting the energy and velocity of the blow it is possible to produce an incipient spall or a fracture through the center of the plate, parallel to its surface, extending approximately over the area of impact which demonstrates existence of tensile stress in the plane of thickness.

Direct bombardment of test specimens by projectiles has many inherent difficulties. However, most of these can be avoided by substituting for the impact of a projectile the impact of a detonating wave traveling through a column of explosive applied directly to the point or area to be tested. This procedure, originally developed for testing ballistic shock resistance of military ordnance, can be readily applied to almost any structural shape.

It is true that a test of this nature, in addition to producing a system of triaxial tension, has several other features the desirability of which is, at best, doubtful. The most important of these is the rapid rate of loading

and hence of stress rise necessary, since the tension stress in the plane of the thickness of the plate, produced by the reflection of the elastic shock wave from the back of the plate, is a direct function of the velocity of impact and is virtually zero at normal rates of loading. Experimental data indicate that velocity of at least 500 meters per second is necessary to produce a force of any appreciable magnitude, and for most effective testing velocities between 1500 and 5000 meters per second are used. A question immediately arises as to whether these high rates of stress and strain rise may not cause the material tested to behave in a different manner than under a relatively static stress system encountered under most service conditions.

Our present knowledge of behavior of metals under high speed loading is rather limited. However, such information as is available indicates that high rates of stress rise tend to decrease uniaxial ductility of cylindrical specimens of uniform cross section and small diameter ($^1/_2$ in. and under) in approximately the same manner as does low temperature. The decrease, however, is not of high order of magnitude and no change from shear to cleavage mode of fracture has been observed on any metal specimen tested. Furthermore, data obtained with the direct explosion or triaxial stress test indicates that high rate of strain, unless combined with triaxial stress, produces little difference in the performance of steel plate from the conventional behavior under standard tensile tests. It is therefore highly probable that the effect of the high rate of strain present in this test is negligible.

As opposed to the presence of these less desirable aspects, the fact remains that the direct explosion method of testing is probably the only practical means available at present of obtaining reasonably uniform triaxial loading of a comparatively large volume of material, e.g., in cases of 1-in. thick plate, roughly 12 cu. in.

## GENERAL

Since notch sensitivity of steel and welded steel joints appears to be an important factor in service performance of fabricated structures of practically every type and description, including ships and other marine vessels, it was considered desirable to develop a reliable test to determine notch sensitivity of steel and of welded steel joints at different temperatures. The direct explosion method of testing would provide such a test if correlation between it and actual service performance could be established.

It is obviously not practical to attempt to determine service performance of various steels and steel joints by destructive testing of actual structures such as ships as both the cost and the time of such an undertaking would be prohibitive.

Fortunately, considerable data exists on performance of a section of a Liberty vessel deck forming a corner of a hatch opening, when tested in tension to destruction under a number of conditions.[3,4] These data reveal considerable difference in performance depending on types of steel, method of fabrication and temperature of test. If the same order and degree of difference could be established for similar conditions under the direct explosion test, a reasonably close correlation with service performance could be expected from this test, and it could be used as a criterion for evaluating materials and fabrication processes.

Accordingly a comprehensive program of tests, duplicating as nearly as possible the conditions investigated at the University of California, by means of the hatch corner type specimen was formulated and carried out under the sponsorship of the Bureau of Ships of the Department of the Navy. As soon as good correlation between the two tests became apparent the program was expanded to include a number of steels and welding procedures of general interest to the Navy Department in an attempt to establish a reasonably broad picture of their relative performance. A total of 14 different steels in prime or unwelded conditions was investigated. Of these steels 10 were also tested as welded with four different classes of electrodes for a total of seventeen steel-electrode combinations.

The steels were tested in the form of 1-in. thick plate and fell roughly into four groups on the basis of conventional mechanical properties as follows:

(*a*) Low-carbon, low-manganese steels, generally known as "mild" steel, widely used in as-rolled condition for ship building and general structural purposes. A rimmed or semikilled steel of approximately 35,000 psi. yield and 60,000 psi. ultimate strength, capable of being produced in large tonnages. Steels $Y_2$, $L_1$ and $L_2$ belong to this group.

(*b*) Low-carbon, medium-manganese steels with or without additions of vanadium and titanium, generally known in Naval construction as high-tensile hull plate, used in either as-rolled or normalized condition. A fully killed steel with approximately 50,000 psi. yield and 90,000 psi. ultimate strength. Steels $Y_1$, $K_1$ and $K_2$ belong to this group.

(*c*) Low-carbon, low-alloy steels with carbon content below 0.20 and sufficient alloy additions to give 75,000–85,000 psi. yield strength in either normalized and tempered or quenched and tempered state. An experimental steel of interest to the Navy Department. Steels F, G, E, B, I, X, A, $R_a$ and $R_b$ belong to this group.

(*d*) Medium-carbon, low-alloy steel with 0.25–0.35% carbon content and sufficient alloy addition to have at least 100,000 psi. yield strength when quenched and tempered. Generally known as Navy's STS grade and used for both structural and ballistic protection purposes. Steel H belongs to this group.

The chemical compositions and mechanical properties of the steel are given in detail in Tables 1 and 2, respectively.

The welded specimens were prepared by butt-welding together two 9- x 18- x 1-in. plates to form an 18-in. square specimen. A 60° double V joint with zero root face and $^5/_{32}$-in. root opening was used. The root of the first pass was chipped out to sound metal and the

**Table 1—Chemical Properties of Steels Tested**

| *Symbol* | *Heat treatment* | *C* | *Mn* | *P* | *S* | *Si* | *Ni* | *Cr* | *Mo* | *V* | *Cu* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| F | Q and D | 0.16 | 0.27 | 0.014 | 0.021 | 0.17 | 2.32 | 1.13 | 0.20 | ... | ... |
| G | N and D | 0.13 | 0.46 | 0.012 | 0.017 | 0.15 | 2.24 | 0.03 | 0.34 | 0.08 | 0.63 |
| E | Q and D | 0.16* | 1.45 | 0.017 | 0.038 | 0.21 | 0.53 | 0.02 | 0.48 | 0.08 | 0.08 |
| B | Q and D | 0.14† | 0.76 | 0.022 | 0.025 | 0.79 | ... | 0.61 | 0.16 | ... | ... |
| I | N | 0.16 | 1.30 | 0.013 | 0.028 | 0.25 | 1.68 | 0.04 | 0.21 | 0.11 | 0.23 |
| $R_a$ | Q and D | 0.17 | 0.83 | 0.020 | 0.030 | ... | 1.69 | ... | 0.22 | ... | 1.10 |
| $R_b$ | Q and D | 0.14 | 0.64 | 0.021 | 0.031 | ... | 1.54 | ... | 0.20 | ... | 1.06 |
| XA | Q and D | 0.19 | 1.08 | 0.014 | 0.023 | 0.24 | 0.17 | 0.046 | 0.42 | ... | 0.16 |
| H | Q and D | 0.25 | 0.23 | ... | ... | 0.27 | 3.15 | 1.33 | ... | ... | ... |
| $Y_1$ | As-rolled | 0.11‡ | 1.35 | 0.020 | 0.030 | 0.22 | ... | ... | ... | ... | ... |
| $Y_2$ | As-rolled | 0.20 | 0.40 | 0.050 | 0.035 | 0.02 | ... | ... | ... | ... | ... |
| $I_2$ | Norm. | 0.23 | 0.81 | ... | 0.032 | 0.03 | 0.02 | 0.02 | 0.03 | 0.00 | 0.03 |
| $K_1$ | Norm. | 0.13§ | 1.21 | 0.021 | 0.033 | 0.32 | 0.19 | 0.10 | 0.03 | 0.08 | 0.30 |

* 0.01 Sn. † 0.08 Zr. ‡ 0.006 Ti. § 0.005 Ti.

**Table 2—Mechanical Properties of Steels Tested**

| *Steel code letter* | *Ingot No. and place* | *Type specimen* | *Direction and position* | *Yield strength, psi., 0.2% set* | *Tensile strength psi.* | *Elongation, % in* | *RA%* | *Average Ft.-lb. Charpy keyhole, −40°F.** |
|---|---|---|---|---|---|---|---|---|
| F | 3M | 505 | Tr. | 82,700 | 100,200 | 25.2 | 68.0 | |
| | | | Long | 79,500 | 100,200 | 27.1 | 75.3 | 64.1 |
| G | 1T | 505 | Tr. | 66,300 | 95,100 | 24.4 | 54.6 | |
| | | | Long | 64,000 | 96,000 | 27.3 | 60.8 | 40.0 |
| E | 1B | 505 | Tr. | 78,500 | 95,100 | 21.3 | 47.6 | |
| | | | Long | 76,800 | 96,100 | 26.3 | 65.8 | 42.3 |
| B | ... | 505 | Tr. | 76,800 | 98,300 | 23.3 | 62.0 | |
| | | | Long | 76,600 | 98,600 | 23.9 | 64.6 | 31.0 |
| XA | ... | 505 | Tr. | 84,200 | 102,000 | 21.0 | 69.5 | |
| | | | Long | 79,900 | 97,800 | 26.3 | 70.9 | 48.0 |
| H | ... | 505 | ... | 100,500 | 126,000 | 22.5 | 66.6 | |
| $Y_1$ | ... | 505 | ... | 48,000 | 90,000 | 30.0 | 60.0 | |
| $Y_2$ | ... | 505 | ... | 32,000 | 60,000 | 32.0 | 65.0 | 3.0 |
| K | ... | 505 | ... | 50,000 | 90,000 | 30.0 | 60.0 | |
| L | ... | 505 | ... | 32,000 | 60,000 | 32.0 | 65.0 | |

* Notch normal to rolled surface.

finished weld was radiographed. All welded joints tested and reported herein were radiographically sound. A few unsound welds were tested in an attempt to determine the effect of radiographic unsoundness.

Four classes of electrodes were used: A.W.S. types 6010, 7016, 10015 and 12015. Class 10015 electrode was in most cases of the manganese-molybdenum type. However, to check the effect of the difference in electrode composition within the same A.W.S. class, a nickel-molybdenum type of 10015 class was also used in one instance. The 12015 class electrode was of the nickel-molybdenum-vanadium type.

The 6010 and 7016 electrodes were used without preheat while 250° preheat was used with class 10015 and 12015 electrodes, except when welding low-carbon medium-manganese Steel K, which was welded with 100° F. interpass temperature.

Type A.W.S. 10015 electrode was selected primarily since the mechanical properties of the weld metal deposited by this electrode are, in as-welded state, approximately the same as those of the high-yield steels used and it was therefore hoped that the over-all performance of the joints made with this electrode would not differ greatly from that of the prime plate.

Type 7016 electrode is a widely used electrode of the low-hydrogen type requiring no preheat and it was felt desirable to use it as a base line in studying the relative weldability of the experimental high-yield-strength steels as compared with other structural steels, and to provide a means of comparing structural performance of one electrode when used on different types of steel. Since it deposits low-strength low-carbon weld metal, it was not expected to produce a tough joint on the high-strength low-alloy steels, and its use in fabrication of the high-yield-strength steels was not contemplated.

Table 3 shows the combinations of steel and electrode investigated.

**Table 3—Steel-Electrode Combinations Tested**

| *Welding electrode* | *Steels* |
|---|---|
| A.W.S. 6010 | Mild steel ($Y_2$) |
| A.W.S. 7016 | Mild, high-tensile and high-yield-strength steels ($Y_2$, $K_1$, XA, I, B, E, F) |
| A.W.S. 10015 Mn-Mo | High-yield-strength steels (B, E, F) |
| A.W.S. 10015 Ni-Mo | High-tensile and high-yield-strength steels ($K_1$, F) |
| A.W.S. 12015 Ni-Mo-Va | High-yield-strength and armor plate (F, H) |
| Submerged melt 0.50 Mo wire | High-yield-strength steels ($R_a$, $R_b$) |

*Fig. 1 Support plate with support bars ready to receive specimen*

*Fig. 2 Specimen resting on support bars, with explosive charge placed on specimen*

Part of cardboard cylinder container, housing explosive, cut away to show detonator

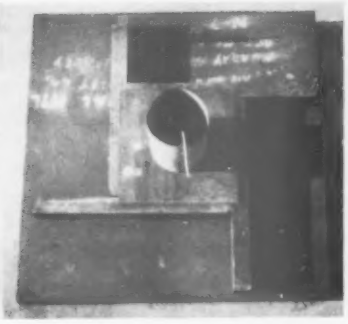

*Fig. 3 Explosive charge placed on specimen and surrounded by paper cylinder ready to receive sand*

## METHOD OF TESTING

The direct explosion or triaxial stress method of testing has been described in detail in a number of reports of earlier investigations.[2,6,7] Briefly, it consists of detonating an explosive charge in direct contact with the specimen supported along its four edges, as follows:

The supports consist of a concrete platform, 6 ft. square, supporting a high-tensile steel plate, 3 ft. square by 3 in. thick. The steel plate in turn supports four steel bars 4 in. high by $2^1/_2$ in. wide, placed to form a hollow square 16 in. inside and 21 in. outside, as shown in Fig. 1. The specimen is placed on the bars and overlaps the hollow square by 1 in. on all four sides, as shown in Fig. 2. A cylindrical explosive charge is prepared by filling a round cardboard container 102 mm. I.D. with a desired weight of specially formulated explosive and compressing it to a desired density. The charge is then placed in the center of the specimen to be tested, as shown in Fig. 2, and surrounded on all sides with approximately 40 lb. of white silica sand held in place by means of a paper cylinder $8^1/_2$ in. in diameter and 12 in. in height, as shown in Fig. 3. The charge is then exploded by means of a special detonator in such a manner that the front of the detonating wave traveling through the charge reaches the face of the specimen nearly simultaneously over the entire area under the charge. The effect of the impact of the wave is to first bend and then stretch the plate equally along its two axes, the amount of deformation being nearly linear with the charge, as shown in Fig. 4.

The minimum charge necessary to fracture the specimen is established by subjecting a number of identical specimens to the action of progressively greater charges until fracture occurs. Each specimen is subjected to the action of only one charge. Figure 5 shows in graphical form the manner in which the minimum energy to fracture is determined. It will be seen that an average of four to six specimens is required for any one point.

In an earlier investigation it was found that test results differed somewhat when 12- and 18-in. sq. specimens were used, but that little difference existed between performance of 18- and 24-in. sq. specimens. The 18-in. sq. specimen was, therefore, selected and used throughout this investigation. It was also found that no difference in performance existed regardless of

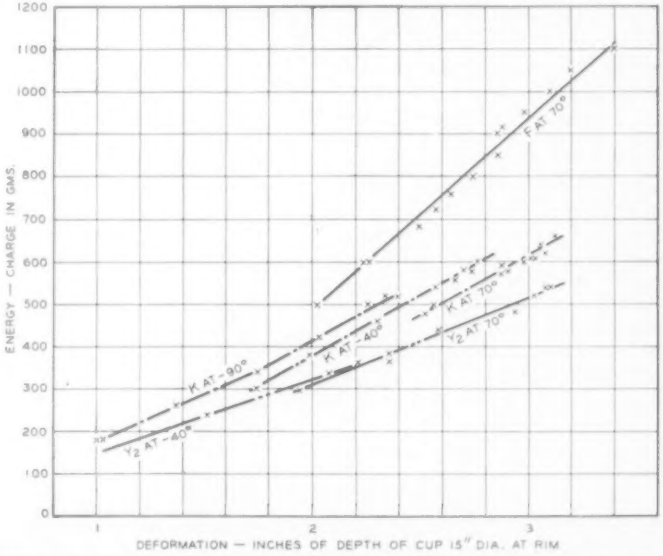


*Fig 4 Deformation of specimen plotted as function of energy applied, for high-yield-strength Steel F, high-tensile Steel K and mild Steel $Y_2$*

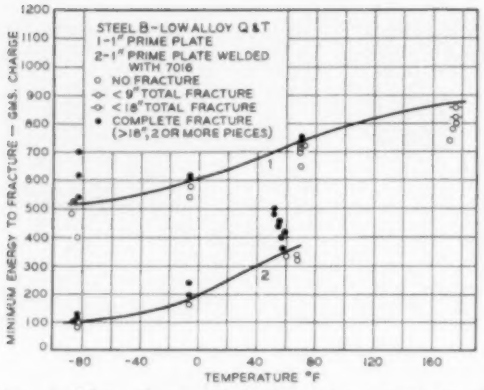
STEEL B-LOW ALLOY Q&T
1-1" PRIME PLATE
2-1" PRIME PLATE WELDED WITH 7016
NO FRACTURE
< 9" TOTAL FRACTURE
< 18" TOTAL FRACTURE
COMPLETE FRACTURE (>18", 2 OR MORE PIECES)
MINIMUM ENERGY TO FRACTURE — GMS. CHARGE
TEMPERATURE °F

*Fig. 5 Effect of successively increasing quantities of energy applied to prime and welded high-yield-strength Steel B, at temperatures between −100° F. and + 180° F.*

whether the support bars were welded together into a solid frame or placed adjacent to each other to form a loose frame. Accordingly, the welding of the support bars was omitted throughout this investigation.

The previous investigation also revealed no significant difference in performance of a high-tensile steel plate when tested with explosives of from 3250 to 4700 meters per second detonating velocities. In general, the amount of deformation prior to fracture and the total energy to fracture decreased with the increase in the velocity of detonation, as was to be expected, since the magnitude of the third tension or the stress in the plane of thickness becomes higher, and its ratio to the two stresses in the plane of the plate becomes lower with the increase in the velocity of detonation. The manner of fracture, however, was substantially the same for all three velocities and was brittle at low temperatures. This appeared to indicate that the lowest velocity tried produced sufficiently high third-dimensional stress to effect brittle failures under some conditions of testing and was, therefore, satisfactory for use with the steels under investigation. On the other hand, in the light of previous experience,[6,7] it appeared probable that the higher detonating velocities may produce too severe a test for steels of lower tensile strength or toughness, because of possible premature failure by spalling. Since it appeared desirable to be able to compare directly the performance of all steels to be investigated, including performance of mild steel, the 3250 meters per second explosive was selected.

The actual explosive mixed and used had a detonating velocity of 3245 meters per second. It was prepared and mixed in one batch of 800 lb., but as an added precaution, it was remixed (or rather 50-lb. batches of it were placed in a laboratory mixer and mixed again) prior to use.

The plates were brought to desired temperature by placing them into a cold box and keeping them at the desired temperature for a period of not less than 4 hr. The cold box used was of the type wherein the source of cold is provided by continuously vaporizing dry ice, and the temperature is regulated by intermittent operation of an electrical heater unit, thus permitting a range of temperatures from approximately −90 to 200° F.

The temperature of the plate was checked immediately prior to testing by bringing a thermometer into direct contact with the surface of the plate while it was in the box. In no instance was it measurably different from the air temperature in the box.

The time interval between the removal of the plate from the box and the detonation was measured and recorded. In no instance did it exceed 2 min.

Some welded plates were found to be slightly distorted due to welding. All such plates were tested with their convex side down to secure direct support of the welded joint at all times.

Since it was desirable to test the welded plates with the weld reinforcement intact, or in the same condition as would be encountered in actual service, the charge had to be raised slightly from the surface of the specimen to clear the weld reinforcement. This was accomplished by supporting the charge on two strips of lucite, 0.100 ±0.002 in. thick, placed parallel to and on each side of the weld. The space between the bottom face of the charge not resting on the lucite and the surface of the plate was filled with sand. To permit direct comparison between welded and prime plate all plates, whether welded or not, were tested in this manner.

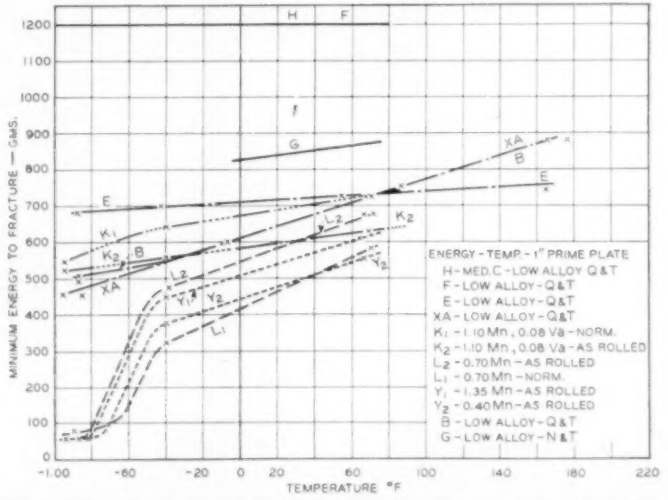
MINIMUM ENERGY TO FRACTURE — GMS.
TEMPERATURE °F
ENERGY - TEMP - 1" PRIME PLATE
H - MED.C - LOW ALLOY Q&T
F - LOW ALLOY - Q&T
E - LOW ALLOY - Q&T
XA - LOW ALLOY - Q&T
K1 - 1.10 Mn, 0.08 Va - NORM.
K2 - 1.10 Mn, 0.08 Va - AS ROLLED
L2 - 0.70 Mn - AS ROLLED
L1 - 0.70 Mn - NORM.
Y1 - 1.35 Mn - AS ROLLED
Y2 - 0.40 Mn - AS ROLLED
B - LOW ALLOY - Q&T
G - LOW ALLOY - N&T

*Fig. 6 Effect of temperature on minimum energy necessary to fracture prime steel plate 1 in. thick. Summary of all steels tested*

**Table 4—Summary of Performance of 1-in. Thick Steel Plate**

(All energies are for complete fracture into two or more pieces, unless followed by * which denotes a ductile failure. Energy expressed as weight of charge in grams, deformation as depth of cup 15 in. of rim, path of fracture as follows: WM—weld metal, HAZ—heat-affected zone, FL—fusion line, PP—plate unaffected by welding, PPF—plate unaffected by welding with fracture starting at the weld.) Minimum energy to fracture, (1) Length (2) and location of fracture (3) and maximum deformation (4) prior to fracture.

| | | | 175° F | | | 70° F | | | 0° F | | | −40° F | | | −80° F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Steel | Condition | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) | (3) | (4) |
| Xc | C-Mn | As-rolled, prime | ... | ... | ... | 560 | 63 in. | PPF | 3.10 in. | ... | ... | 380 | 72 in. | PPF | 60 | 42 in. | PPF | 0.00 in. |
| Xc | C-Mn | Welded, 6010 electrode | ... | ... | ... | 380 | 53 in. | PPF | 2.38 in. | ... | ... | 40 | 29 in. | PPF | 30 | 41 in. | PPF | 0.00 in. |
| Xc | C-Mn | Welded, 7016 electrode | ... | ... | ... | 460 | 52 in. | PPF | 2.53 in. | ... | ... | 40 | 44 in. | PPF | 30 | 36 in. | PPF | 0.00 in. |
| Ld | C-Mn | As-rolled, prime | ... | ... | ... | 680 | 51 in. | ... | 3.30 in. | ... | ... | 430 | 102 in. | ... | 100 | 74 in. | ... | 0.00 in. |
| Ld | C-Mn | Normalized, prime | ... | ... | ... | 580 | 52 in. | ... | 3.08 in. | ... | ... | 320 | 80 in. | ... | 80 | 40 in. | ... | 0.00 in. |
| Yc | C-Mn | As-rolled, prime | ... | ... | ... | 610 | 38 in. | ... | 2.95 in. | ... | ... | 460 | 92 in. | ... | 60 | 31 in. | ... | 0.00 in. |
| Ke | C-Mn-Va | As-rolled, prime | ... | ... | ... | 630 | 28 in. | ... | 2.97 in. | ... | ... | 560 | 90 in. | ... | 520 | 90 in. | ... | 2.22 in. |
| Ke | C-Mn-Va | Normalized, prime | ... | ... | ... | 720* | 27 in. | ... | 3.10 in. | ... | ... | 680 | 41 in. | ... | 540 | 79 in. | ... | 2.39 in. |
| Ke | C-Mn-Va | Welded-7016 electrode | ... | ... | ... | 660* | 21 in. | HAZ | 2.90 in. | ... | ... | 580 | 55 in. | PPF | 440 | 42 in. | PPF | 0.41 in. |
| Ke | C-Mn-Va | Welded-10015 electrode | ... | ... | ... | 660* | 17 in. | HAZ | 2.78 in. | ... | ... | 480 | 38 in. | PPF | 260 | 32 in. | PPF | 0.59 in. |
| Ra | Mn-Ni-Mo-Cu | Quenched and tempered, prime | ... | ... | ... | 720 | 18 in. | ... | 1.77 in. | ... | ... | ... | ... | ... | 400 | 18 in. | ... | 0.96 in. |
| Ra | Mn-Ni-Mo-Cu | Welded, submerged melt, Mn-Mo wire | ... | ... | ... | 360 | 18 in. | FL | 1.01 in. | ... | ... | ... | ... | ... | 120 | 33 in. | FL-PPF | ... |
| Rb | Mn-Ni-Mo-Cu | Quenched and tempered, prime | ... | ... | ... | 680 | 36 in. | ... | 2.12 in. | ... | ... | ... | ... | ... | 440 | 113 in. | ... | 1.38 in. |
| Rb | Mn-Ni-Mo-Cu | Welded, submerged melt, Mn-Mo wire | ... | ... | ... | 420 | 18 in. | FL | 1.54 in. | ... | ... | ... | ... | ... | 180 | 48 in. | FL | 0.48 in. |
| E | Mn-Ni-Mo-Va | Quenched and tempered, prime | 690* | 15 in. | ... | 720 | 18 in. | ... | 2.58 in. | 620 | 90 in. | 700 | 18 in. | ... | 680 | 42 in. | ... | 2.21 in. |
| E | Mn-Ni-Mo-Va | Welded, 7016 electrode | ... | ... | ... | 590 | 18 in. | WM* | 2.07 in. | 270 | 18 in. | WM | 2.47 in. | ... | 180 | 18 in. | WM | 0.54 in. |
| E | Mn-Ni-Mo-Va | Welded, 10015 electrode | ... | ... | ... | 560 | 18 in. | HAZ | 2.06 in. | ... | ... | ... | ... | ... | 280 | 41 in. | PPF | 0.95 in. |
| XA | Mn-Mo | Quenched and tempered, prime | 840* | 15 in. | ... | 750 | 18 in. | WM* | 2.42 in. | 620 | 90 in. | 2.04 in. | ... | ... | 450 | 93 in. | ... | 1.39 in. |
| XA | Mn-Mo | Welded, 7016 electrode | ... | ... | ... | 480 | 18 in. | ... | 1.69 in. | 390 | 18 in. | WM | 1.03 in. | ... | 40 | 19 in. | PPF | 0.00 in. |
| B | Mn-Si-Cr-Mo-Zr | Quenched and tempered, prime | 840* | 3 in. | ... | 740 | 69 in. | WM* | 2.46 in. | 620 | 93 in. | 2.10 in. | ... | ... | 510 | 100 in. | PPF | 1.73 in. |
| B | Mn-Si-Cr-Mo-Zr | Welded, 7016 electrode | ... | ... | 2.75 in. | 360 | 20 in. | WM* | 1.50 in. | 200 | 39 in. | WM | 0.59 in. | ... | 100 | 50 in. | PPF | 0.38 in. |
| B | Mn-Si-Cr-Mo-Zr | Welded, 10015 electrode | ... | ... | ... | 640 | 37 in. | FL | 2.16 in. | 280 | 60 in. | HAZ | 1.02 in. | ... | 100 | 29 in. | PPF | 0.38 in. |
| I | Mn-Mo | Normalized and tempered, prime | ... | ... | ... | 870* | 7½ in. | ... | 2.98 in. | 820 | 32 in. | ... | 2.52 in. | ... | ... | ... | ... | ... |
| I | Mn-Mo | Welded, 7016 electrode | 680* | 9 in. | FL | 640 | 86 in. | WM* | 2.19 in. | 280 | 18 in. | WM | 1.01 in. | ... | 580 | 135 in. | PPF | 1.85 in. |
| I | Mn-Mo | Welded, 10015 electrode | ... | ... | 2.02 in. | 490 | 20 in. | ... | 1.88 in. | ... | ... | ... | ... | ... | 90 | 59 in. | PPF | 0.14 in. |
| G | Ni-Cu-Mo-Va | Normalized and tempered, prime | ... | ... | ... | 870* | 7½ in. | ... | 2.98 in. | 820 | 32 in. | ... | 2.52 in. | ... | ... | ... | ... | ... |
| F | Ni-Cr-Mo | Quenched and tempered, prime | ... | ... | ... | 1200 | 9 in. | WM* | 3.29 in. | 440 | 18 in. | WM | 1.38 in. | ... | 1200* | 7 in. | WM | 2.74 in. |
| F | Ni-Cr-Mo | Welded, 7016 electrode | ... | ... | ... | 610 | 18 in. | ... | 2.22 in. | ... | ... | ... | ... | ... | 210 | 18 in. | ... | 0.76 in. |
| F | Ni-Cr-Mo | Welded, 10015 Ni-Mo electrode | ... | ... | ... | 1200* | 7½ in. | FP | 2.92 in. | 800* | 16 in. | FL | 2.03 in. | ... | 460* | 9 in. | HAZ-WM | 1.61 in. |
| F | Ni-Cr-Mo | Welded, 12015 Ni-Mo-Va electrode | ... | ... | ... | 1100* | 12 in. | FL | 2.88 in. | ... | ... | ... | ... | 680* | 16 in. | HAZ | 420* | 17 in. | HAZ-WM | 1.33 in. |
| H | Ni-Cr | Quenched and tempered, prime | ... | ... | ... | 1100* | 12 in. | PPHAZ | 2.75 in. | ... | ... | ... | ... | 560* | 12 in. | FL | 1.84 in. | 420* | 12 in. | HAZ-WM | 1.19 in. |
| H | Ni-Cr | Welded, 12015 Ni-Mo-Va. | ... | ... | ... | 1240* | 7½ in. | ... | 2.73 in. | ... | ... | ... | ... | ... | ... | ... | ... | 1120* | 8 in. | ... | ... |
| | | prime | ... | ... | ... | 420 | 18 in. | FL | 1.13 in. | ... | ... | 400 | 18 in. | FL | 1.11 in. | 400 | 18 in. | FL | ... | ... | 1.05 in. |

In testing notch-tough steel at all temperatures and notch-sensitive steels at elevated temperatures, it was observed that considerable difference exists between energy necessary to cause the first crack on the back of the plate and energy necessary to effect complete fracture. Since no such difference exists in the case of notch-sensitve plates at low and room temperatures, the extent of this difference is of considerable interest, and an attempt was made in all cases to determine the energy necessary to effect a complete fracture as well as the energy necessary to produce incipient failure.

In cases of some exceptionally tough steels it was not always possible to fracture the specimen into two pieces, since the impact tended to punch a hole through the plate, and once this occurred any further increase in energy applied had little further effect.

## DISCUSSION OF RESULTS

The results of the test data obtained are summarized in Table 4 and compared in graphical form in Figs. 6–10. The appearance of typical specimens after test is shown in Figs.11–22.

A study of the test data revealed that, with the exception of one steel, there is virtually no scatter in the performance of the specimens tested. In a few instances charges of equal weight fractured one specimen but

would not fracture an identical specimen tested under identical conditions. In all such cases, however, a 2 to 3% difference in the weight of the charge was sufficient to differentiate between the performance of identical specimens. This lack of scatter indicates, first of all, homogeneity of the plates tested, and what is even more important, it demonstrates clearly the consistency of the test itself, since the existence of a variable of any appreciable magnitude in the test would be bound to result in some scatter.

The one exception, Steel I, where some scatter oc-

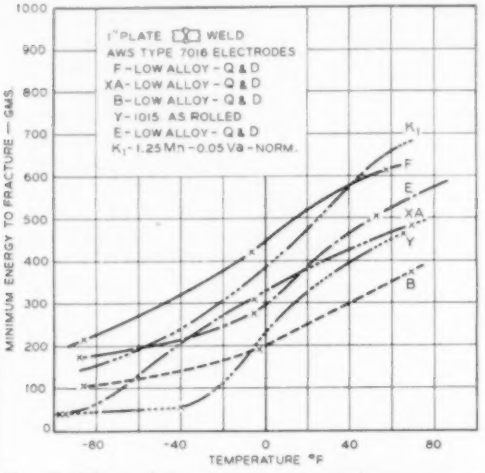
1" PLATE ☒ WELD
AWS TYPE 7016 ELECTRODES
F - LOW ALLOY - Q & D
XA - LOW ALLOY - Q & D
B - LOW ALLOY - Q & D
Y - 1015 AS ROLLED
E - LOW ALLOY - Q & D
K1 - 1.25 Mn - 0.05 Va - NORM.
MINIMUM ENERGY TO FRACTURE — GMS.
TEMPERATURE °F

*Fig. 7 Effect of temperature on minimum energy necessary to fracture 1-in. thick steel plate welded with A.W.S. Type 7016 electrode*

**High-yield-strength steels F, E, B and XA, high-tensile Steel K and mild Steel Y₂**

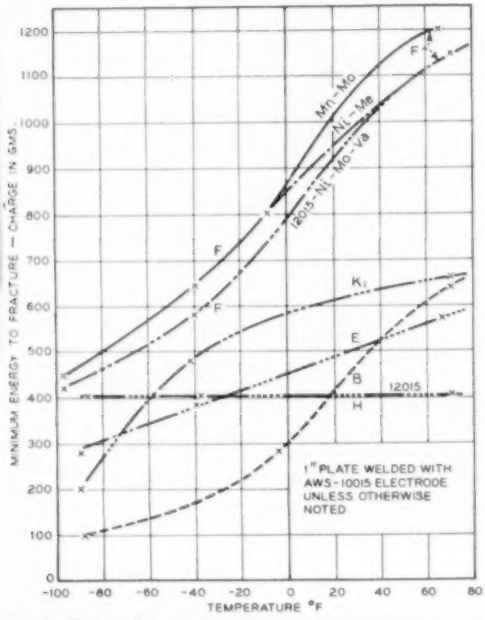


*Fig. 8 Effect of temperature on minimum energy necessary to fracture 1-in. thick steel plate welded with A.W.S. Type 10015 and Type 12015 electrodes*

**High-yield-strength steels F, E and B, high-tensile Steel K₁ and STS Steel H**

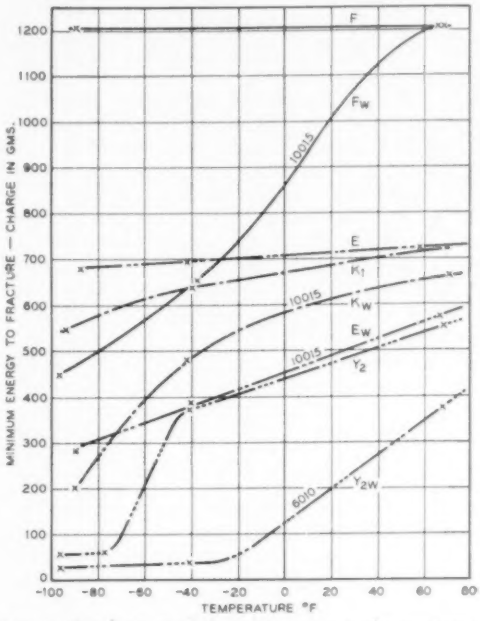


*Fig. 9 Comparison of the minimum energies necessary to fracture prime steel plate 1 in. thick and a welded joint made from the same steel*

**High-yield-strength steels F and E, high-tensile strength Steel K₁ and mild Steel Y₂**

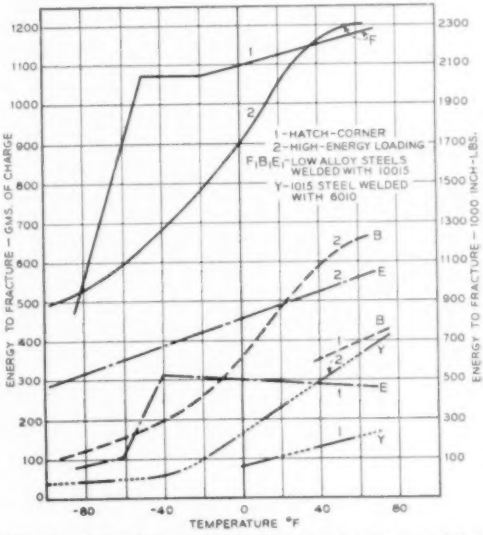
1 - HATCH - CORNER
2 - HIGH - ENERGY LOADING
F, B, E, I - LOW ALLOY STEELS WELDED WITH 10015
Y - 1015 STEEL WELDED WITH 6010
ENERGY TO FRACTURE — GMS. OF CHARGE
ENERGY TO FRACTURE — 1000 INCH-LBS.
TEMPERATURE °F

*Fig. 10 Comparison of results obtained by testing welding joints by the direct explosion test and by the University of California hatch corner type specimen test*

**High-yield-strength steels F, E and B, and mild Steel Y₂**

*Fig. 11 Typical fracture of extremely notch tough 1-in. prime steel plate F at temperatures down to −95° F.*

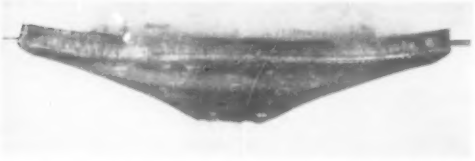

*Fig. 12 Typical fracture of extremely notch tough 1-in. prime steel plate F at temperatures down to −95° F.*

curred, has exhibited the same lack of uniformity under mechanical tests and it is therefore reasonably certain that this scatter is due to nonhomogeneity of the plate.

The consistency of the test is also indicated by the relationship between the magnitude of the charge and the extent of the physical deformation it produces in the specimen. Figure 4 shows this relationship in terms of depth of a cup 15 in. in diameter at the rim, for both prime and welded plate. Although, with the possible exception of Steel F, the quantity of data for any one steel is not sufficient to justify positive conclusions, the total data for all tests considered as a whole indicates a consistent relationship between the charge and the deformation. A certain amount of scatter is present but it does not exceed 3 to 4% for identical specimens and test conditions, and can be accounted for by variation in the thickness of the plate and variation in the flatness of the specimen prior to testing. As a matter of fact, these two features together would produce at least 3% scatter.

It would, of course, be possible to correlate thickness and degree of flatness of each specimen with the extent of deformation produced. However, this was not considered worth while since measurement of the depth of the cup produced by the explosion is, in itself, a rather crude method of measuring strain of the specimen. A more accurate method would be to mark the back of the specimen with a cross-sectional grid of known dimensions and note the change in those dimensions after explosion. It is hoped that such strain measurements will be made in future investigations.

It will be noted that little apparent difference exists in the deformation of welded vs. nonwelded specimens. A definite decrease in deformation does exist, however, with decrease in temperature, which is to be expected.

In general, the behavior of all steels tested differed in two ways, depending on the steel and temperature of the test: a very large difference existed in the amount of energy the specimen would absorb by plastic flow prior to fracture, and a further difference existed in the type and extent of fracture once it occurred.

Based on energy absorption capacity prior to fracture the steels tested in prime condition fell into three general groups, while based on difference in behavior during fracture the steel can be divided into two distinctly different types.

Perhaps the best way to describe the behavior during fracture of the first or tough type is to say that it be-

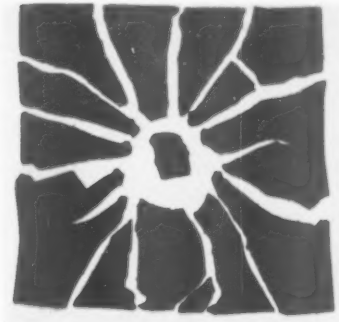

*Fig. 13 Typical fracture at subzero temperatures of 1-in. prime plate having poor resistance to propagation of fracture. (High yield-strength Steel B)*

*Fig. 14 Shear type fracture at minimum energy to fracture of 1-in. prime plate of high-yield-strength Steel E having poor resistance to propagation of fracture in the direction of rolling*

*Fig. 15 Typical fracture at minimum energy, of a welded joint made with notch-sensitive weld metal on tough plate where fracture takes place entirely in the weld metal. (Steel F welded with 7016 electrode)*

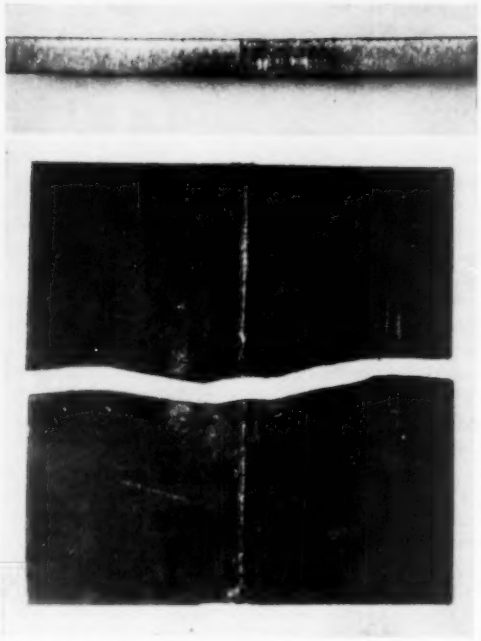

*Fig. 16 Typical fracture at subzero temperature and at minimum energy of a welded joint failing entirely through the parent metal, with the fracture apparently originating in or near the weld. (Steel X A welded with 7016 electrode)*

haves under the high-energy loading test essentially in the same manner as it would under any other mechanical tensile test. A specimen of this group deforms plastically until the limit of elongation is reached at a point or area of maximum stress. If additional energy is still available the specimen fails at the point or line of maximum strain, the degree and extent of failure being directly proportional to the amount of the energy applied. Since the loading of the specimen, and hence the stress field, is not uniform over the entire specimen, the fracture does not propagate through the entire specimen but is confined to the area of maximum strain which appears to coincide with the area of maximum stress. Since the area of maximum stress and strain is essentially a circle corresponding roughly to the area of the charge, the failure in that area or under the charge provides a circular opening which relieves the load produced by the impact of the explosion and further fracture is no longer proportional to the energy applied. Exactly the same behavior can be expected if a slowly moving punch were substituted for the energy of the explosive. The punch would deform the specimen and eventually shear a hole through its center, after which it would apply no further load to the specimen. The fracture in this group is always of the shear type, usually running at 45° to the surface of the specimen. Of the steels tested only one, Steel F, a nickel-chromium-molybdenum, quenched and tempered high-yield steel, behaved in this manner at all temperatures down to −90° F. A similar high-yield low-alloy steel, G, and a high-tensile steel, K, exhibited notch tough behavior at room temperature but changed to cleavage mode of fracture at 0° F. Only high-yield-strength steels were tested at elevated (175° F.) temperatures where they all behaved in notch-tough manner.

It is interesting to note that difference in the total energy necessary to produce a fracture of comparable magnitude in notch-tough steels is of a quite different order of magnitude than what could be expected from their conventional mechanical properties. Thus high-yield Steel F at room temperature absorbs over 40% more energy before fracture than does steel G, and about the same amount as special treatment Steel H, whereas Table 2 indicates that conventional energy absorption of Steel F, as determined by the area under its stress strain curve, is only approximately 5% greater than that of Steel G and approximately 10% less than that of Steel H.

*Fig. 17 Typical fracture at subzero temperature of a welded joint failing primarily through the heat-affected zone. (Steel F welded with 10015 electrode)*

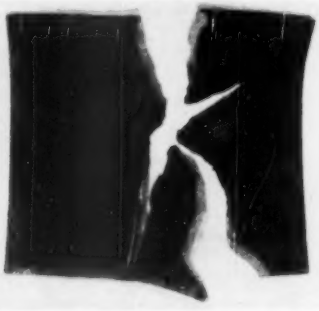

*Fig. 18 Typical fracture at minimum energy to fracture of a welded joint failing through the heat-affected zone and parent plate. (Steel B welded with 10015 electrode)*

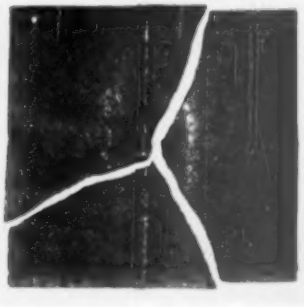

*Fig. 19 Typical fracture at minimum energy and room temperature of a welded joint failing through the parent plate, with the fracture apparently originating in or near the weld*

Similar to Fig. 16, but use of 10015 weld metal resulted in greater energy absorption and greater defo. mation prior to fracture

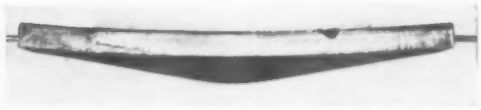

*Fig. 20 Typical maximum deformation of 1-in. prime plate prior to fracture of low-alloy Steel X4 at subzero temperature*

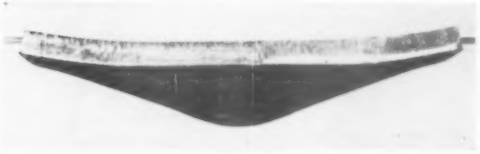

*Fig. 21 Typical maximum deformation of 1-in. prime plate prior to fracture of tough low-alloy Steel F at subzero temperature*

*Fig. 22 Fracture of welded joint made from tough low-alloy Steel F with 10015 electrode at room temperature*

In considering the behavior of the second or notch-sensitive type, probably the most significant difference is found in the fact that in these steels the fracture, after starting at the point of maximum stress, or in the case of welded joints at the point of minimum strength, proceeds in a random manner across the entire specimen, often traveling through areas of very low stress, until the end of the physical continuity of the specimen is reached at its edge. In some cases at room temperature, and in most cases at subzero temperatures, the fracture divides and subdivides into a multitude of paths so that the specimen breaks into many pieces. The fracture is usually of the cleavage type associated with failures of brittle materials.

It will be noted that in the direct explosion test the change from shear to cleavage mode of fracture is not accompanied by a drastic drop in energy absorption capacity as happens in the Charpy or Izod test, although, in general, the specimens failing by shear absorbed more energy prior to fracture than did the specimens failing by cleavage. Thus the energy absorption of high-yield Steel G is only 7% lower at 0° F. than at 70° F., even though the mode of fracture changes from all cleavage to all shear at some point between these two temperatures. Furthermore, it is possible for one steel to fail by cleavage fracture, yet absorb more energy prior to fracture than for another steel which fails by shear fracture.

However, minimum energy to fracture does not tell a complete story since it only expresses the energy necessary to initiate the fracture and does not take into account the energy necessary to propagate the fracture after initiation. As was previously pointed out, the extent of fracture in notch-tough steels is roughly proportionate to the energy applied, whereas in notch-sensitive steels the length of fracture becomes exponential with the energy applied once fracture is initiated. Thus it would appear that a structure made of notch-tough steel may fail locally and still perform its over-all load-carrying function, while it is reasonably certain that a local failure in a structure made from notch-sensitive steel will start a progressive failure culminating in complete collapse even though the structure as a whole may be only lightly loaded.

In general, however, it appears that notch-tough steels absorb considerably more energy before failure than do the notch-sensitive steels, particularly at low temperature. Certainly both steels F and G performed very much better, particularly at low temperature, than any other steel.

Another interesting fact is that the sudden sharp drop in energy absorption prior to fracture may occur long after 100% cleavage failure begins to take place. Thus minimum energy to fracture mild steel $Y_2$ drops from 380 gm. to 60 gm. between −40 and −90° F., even though fracture by cleavage occurs all the way up to and including room temperature. This decrease in energy absorption manifests itself in even more spectacular form in terms of plastic flow prior to fracture: whereas Steel $Y_2$ at −40° F. formed a cup 2.21 in. deep prior to failure, at −90° F. it failed without any plastic deformation whatsoever.

In fact, in several such cases the elastic strain which occurred prior to failure was not sufficient to fracture the mill scale, which remained intact on the surface of the specimen, holding the pieces together and giving an illusion of an intact plate.

The sudden drop in energy absorption within a comparatively narrow temperature range was not observed in any of the steels containing alloy additions, tested as prime plate, the decrease in energy absorption being linear, or nearly linear, in all cases down to −90° F. or the lowest test temperature.

Steel E presents an interesting case in so far as it appears to belong to some extent to both groups. Although the ease with which it sustains complete fracture places it into the second or brittle group, it fails at temperatures down to −40° F. with the typical shear fracture. This is apparently due to its extremely directional properties as fracture in this steel always travels along the line of rolling of the plate. It is thus possible for steel to fail in a shear or ductile manner and yet exhibit the poor resistance to fracture propagation of the notch-sensitive steels.

Based on their ability to absorb energy prior to fracture, the steels tested as prime plate fell broadly into three groups: steels showing no decrease in energy absorption property down to −90° F., steels showing a moderate and nearly linear decrease in energy absorption with decrease in temperature and steels showing a very large and sudden decrease in energy absorption within a narrow temperature range.

The first group had approximately double the energy

absorption capacity of the second group, while the second group, though only slightly higher in energy absorption than the third group at room temperature, had nearly ten times the energy absorption capacity of the third group at −90° F., or after the occurrence of a steep drop in energy absorption properties somewhere between −40 and −90° F. Referring to Fig. 6, it will be seen that only one steel, F, falls into the first group while all the other low-alloy steels tested, as well as the manganese-titanium-vanadium Steel K, fall into the second group. All mild steels tested as well as the high-manganese high-tensile Steel $Y_1$ form the third group.

It is interesting to note that this grouping of steels does not bear any definite relation to either their chemistry, heat treatment or conventional mechanical properties. For instance, the total alloy content of steels F, R and I, as well as their conventional mechanical properties, were very nearly the same, while on the other hand, Steel K had very much lower alloy content and yield strength than either F, R or I. Yet Steel F was in Class 1 all by itself, while steels R, I and K were in Class 2, with Steel K definitely superior to either R or I at low temperatures. Similarly, the only apparent difference in chemistry between Steel K and Steel $Y_1$ was an addition of 0.08 vanadium and 0.005 titanium in the former while their mechanical properties were nearly identical, yet Steel $Y_1$ very definitely belongs to the third group, its energy absorption dropping from 375 to 60 gm. between −40 and −90° F.

In reviewing the performance of welded joints tested it becomes immediately apparent that the presence of the weld lowers the energy absorption capacity or toughness of the prime plate to a marked degree and that the decrease in toughness becomes progressively more pronounced with the decrease in temperature.

Figures 7 and 8 compare performance of joints made with A.W.S. Class 7016 and 10015 electrodes, respectively, while Fig. 9 compares performance of prime plate with performance of welded joints for several steels and electrodes.

In examining Figs. 7 and 8 it will be seen that although in general the performance of the welded joint is influenced by both the steel and the electrode, the relationship is neither consistent nor simple. Thus referring to joints made with 7016 electrode the most pronounced difference occurred between steels F and $Y_2$ at subzero temperatures, which would seem logical since F in prime state was also the toughest, while $Y_2$ was the least tough of all the steels tested. However, at room temperature Steel $Y_2$ as welded with 7016 electrode performed considerably better than Steel B, despite the fact that in the prime state B was much tougher than $Y_2$. Furthermore, Steel $K_1$ which in prime state is less tough than Steel E and only a little better than Steel B, was greatly superior to B at all temperatures and superior to E down to −40° F. when welded with 7016 electrode.

Again, considering the same steels welded with Class 10015 and 12015 electrodes, it will be seen that although, in general, considerable improvement has been effected by the use of tougher weld metal the improvement is by no means uniform, nor, again, is the general performance of the joint a simple function of the performance of the plate forming the joint. Thus, referring to joints made with 10015 electrodes, while Steel F again shows best performance Steel $K_1$ shows a very marked improvement, with steels E and B exhibiting hardly any improvement. Perhaps the key to this apparent inconsistency lies in the fact that the over-all strength of the welded joint is no greater than the strength of any one of its three major components: weld-metal, fusion zone and heat-affected zone. Thus increasing the toughness of the weakest of the three would merely throw the fracture into the next weakest zone without necessarily increasing the strength of the joint.

An examination of the path of fracture of the various joints reveals that in general this is what does actually take place in the majority of cases. Thus Steel F, welded with 7016 electrode, failed by fracture of the weld metal at all temperatures, whereas Steel $K_1$ welded with 7016 electrode, failed at approximately the same energy input but by fracture through the heat-affected zone at room temperature, and through the parent plate at subzero temperature. On the basis of this performance it could then be expected that the use of tougher weld metal would improve performance of Steel F but not of Steel K. Actually, Steel F, welded with 10015 electrode, did perform uniformly better at all temperatures while K did not show any improvement at room temperature when welded with 10015 electrode. However, at subzero temperature the use of tougher weld metal did result in almost 100% improvement in performance of Steel $K_1$ despite the fact that the path of fracture appeared to follow the same general pattern as in the case of joints made with 7106 electrodes.

In the case of Steel E fracture took place through the 7016 weld metal at all temperatures, while the use of 10015 weld metal shifted the fracture into the heat-affected zone at all temperatures down to −40° F. and into the parent plate at −90° F. The increase in energy required to fracture the joint made with 10015 electrode was more pronounced at subzero temperature than at room temperature, indicating that the toughness of 7016 weld metal decreased more rapidly with decrease in test temperature than did the toughness of the heat-affected zone, and that in both cases the toughness of the fusion line was greater than that of either the 7016 weld metal or of the heat-affected zone.

Steel B failed mostly through the weld metal at room temperature and through the fusion line and parent metal when welded with 7016 electrode. When welded with 10015 electrode Steel B failed through the fusion line at room temperature at very much higher energy input. At 0° F. the use of 10015 electrode shifted the fracture into the heat-affected zone but with a comparatively lower increase in energy absorption capacity, while at −90° F. both the path of fracture and the energy to fracture were identical for both electrodes.

Two unexplained phenomena emerge from the above survey of the path and manner of failures, as follows:

1. The strength of the weld metal under triaxial loading appears to be a function of both its mechanical properties and of the chemistry of the steel it joins.

2. The strength of the welded joint under triaxial loading is a function of the electrode composition even in cases where the fracture, though appearing to originate in or near the weld, is confined entirely to the parent metal.

Both of the above anomalies are too well pronounced to be dismissed as accidental. Thus the strength of 7016 weld metal at room temperature varies from the maximum of 610 gm. for Steel F to a minimum of 360 gm. for Steel B, while at zero degrees the percentage difference is even greater, varying from 440 gm. for Steel F to 200 gm. for Steel B.

Similarly, the strength of Steel $K_1$ at $-40°$ F. is nearly doubled when 10015 electrode is used instead of 7016, despite the fact that in both cases the pattern and length of fracture is almost entirely confined to parent plate, the only failure in the weld area being when the fracture crosses the line of weld at right angle to its longitudinal axis.

A possible explanation of the first anomaly may lie in the fact that the severity of the triaxial stress field is greatest in the middle of the plate halfway between its two surfaces and that the fracture, in all probability, originates there. Such stress distribution is indicated by the theoretical analysis of the stress system involved and is substantiated by observations of the origin of the fracture during this and previous investigations. The weld metal in the middle of the plate, however, is that of the root bead or of the first pass which is to a large extent diluted with the parent plate and is thus affected by its chemistry and properties.

The second anomaly presents a more perplexing case. The general pattern of the fracture, traversing as it does the weld at right angles to its longitudinal axis, suggests the possible influence of the residual weld stress, at least in cases where it is not preceded by plastic flow. The fact, however, that the same phenomenon occurs in fractures which are preceded by appreciable plastic flow, points out that the role played by the residual stress is, at most, secondary. Furthermore, since the magnitude of the residual stress is, if anything, greater in the case of 10015 electrode than in the case of 7016 electrode, its existence cannot in any way explain the superior performance of the former. Accordingly, a plausible explanation must await a better understanding of the mechanism of fracture under triaxial stress.

In studying Fig. 9 perhaps the most startling fact is the very wide difference existing under conditions of triaxial stress in energy to fracture of materials which, under conventional tensile tests, do not differ by more than at most 50%. Thus, at room temperature the energy to fracture of low-alloy Steel F welded with 10015 electrode is double the energy to fracture of alloy Steel E, welded with the same electrode, and $3\frac{1}{2}$ times the energy to fracture of mild steel welded with 6050. This difference becomes even more pronounced as temperatures decrease. Thus at 30° F. low-alloy Steel F, welded with 10015 electrode as energy to fracture four times greater than mild Steel $Y_2$ welded with 6010 electrode, while carbon-manganese-vanadium bearing Steel $K_1$, welded with 10015 electrode, is two and a half times as tough as Steel $Y_2$ welded with 6010 electrode. At $-40°$ F. these differences become twenty and sixteen times, respectively. The superiority of Steel $K_1$ is particularly interesting since it is a normalized rather than a quenched and tempered steel, and since it can be welded with 10015 electrode without preheat necessary to weld Steel F.

Another extremely significant fact is that apparently under conditions of triaxial stress practically all welded joints require lower energy to fracture than the prime plate joined by the weld. This decrease in toughness becomes more pronounced as temperature decreases, and reaches considerable proportions at temperatures as high as 30° F. Thus energy to fracture of mild Steel $Y_2$ when welded with 6010 electrode, drops nearly 50% at 30° F. and over 90% at $-40°$ F.

As stated before, one of the objectives of this investigation was to establish the degree of correlation existing between the direct explosion test and the hatch corner type specimen test developed at the University of California. It will be remembered that University of California investigators reported that the hatch corner type specimens fabricated from Type F steel and welded with Class 10015 electrode, required three to four times the energy to fracture than did similar specimens fabricated from steels E and B. This compares closely with the results obtained in this investigation, as will be seen from Fig. 10, which reproduces the results obtained at California as well as the results of the present investigation.

If anything, the hatch corner test appears more severe than the explosion test since it shows greater difference percentage-wise between Steel F and Steels E and B. It must be remembered, however, that in the direct explosion test the reported energy to fracture in the case of notch-tough steel such as F is the energy necessary to effect a partial fracture and should be increased by a considerable amount to be exactly comparable to the energy necessary to effect complete fracture reported in the hatch corner tests.

With this qualification it will be seen that the results of both tests parallel each other very closely, even to the point where both tests show Steel B to be somewhat better at room temperature than Steel E, but not as good at lower temperatures.

A mention was made in the general discussion that evidence exists that high rate of strain, unless combined with triaxial stress, does not appreciably affect performance of welded joints. The data supporting this statement was obtained as part of a related but incompleted investigation of the effect of the geometry of the welded joint. During this investigation it was established that the performance of the weld was equal to that of the parent plate regardless of the temperature of the test as long as the weld was outside of the area covered by the charge. Not only did the specimens con-

taining such welds absorb the same energy as prime plate specimens, but the amount of plate deformation sustained by the weld without fracture was greater than in specimens where the weld, or a part of it, was located under the charge. Since it is reasonable to assume that the rate of plastic strain is nearly the same throughout the specimen at any one time, it follows that the high rate of strain present in this test is not responsible for the poor performance of the welded joint under this test.

## CONCLUSIONS

On the basis of the data obtained in this investigation the following tentative conclusions appear to be reasonable:

(*a*) Good correlation appears to exist between the load-carrying capacity of welded joints as determined by the direct explosion test and by the static loading to destruction of a fabricated structure containing steep stress gradient (hatch corner type specimens).

(*b*) Wide differences appear to exist in the energy necessary to fracture and in the extent of plate deformation prior to fracture of ferritic steel plate, particularly at subzero temperatures, depending on the chemistry and heat treatment.

(*c*) The strength of welded joints is in nearly all cases lower than the strength of the plate forming the joints, the decrease becoming severe at below freezing temperatures.

(*d*) The strength of a welded joint made with 6010 electrode from carbon-manganese steel is only half the strength of the prime plate at 30° F. and one-tenth at −40° F.

(*e*) The strength of the welded joint can be greatly improved by the use of proper alloy electrodes.

(*f*) The strength of the welded joint cannot be predicted from the performance of the plate forming the joint and of the weld metal, but is a complex function of both.

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# The High-Frequency Notch-Bend Test


***An economical method for determining the applicable welding procedure for ferritic steels is indicated and the necessary proof for the validity of the procedure is presented***



*by Bela Ronay*


FABRICATION by arc welding has reached the stage which makes it mandatory for the designer to have information not only concerning the mechanical properties of the steels he intends to specify, but also whether the materials can be fabricated by arc welding producing joints of the desired efficiency by employing techniques which can be executed conveniently and at costs commensurate with the character of the structures involved. For information concerning the applicable welding procedure for a given steel, the designer turns to the Welding Engineer.

This assignment includes two separate problems: namely, the development of the applicable welding procedure, and the selection of the applicable filler metal. Welding Engineers often combine the two problems and attempt to determine the applicable welding procedure and the suitability of electrodes by fabricating weldments wherein either one or more factors are kept constant at a time. Neither of these procedures represent the scientific approach, both are costly and in combination leave the accomplishment to chance. The scientific approach to the problem is to determine separately the applicable welding procedure and the suitability of the applicable welding electrodes. Welding Engineers are fully aware of the desirability of the above and would apply the twin procedures if the methods for their application were standardized.

This paper presents an economical method for determining the applicable welding procedure for ferritic steels; the validity of this procedure was proved in use during the past six years.


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The opinions given in this paper are those of the author and do not necessarily coincide with the official views of the Navy Departments.

## BASIS FOR METHOD

The procedure was based on the empirical knowledge that metallurgical changes occurring in the heat-affected zones of multipass arc welds, executed in accordance with acceptable practices, are for a given steel consistently comparable regardless of the thickness of the material in excess of $^1/_2$ in. This contention was confirmed mathematically by the Rensselaer Polytechnical Institute group of research workers.

It follows then that it is practicable synthetically to produce within a restricted portion of a specimen of suitable volume and geometry the same metallurgical change which occurs within the heat-affected zones of a multipass arc weld produced in companion materials. This can be accomplished by the application of an appropriate heat source and heating method such as high-frequency induction.

Evaluation of the synthetically produced metallurgical change as regards serviceability of the weldment was based on determining the degree of the concurrent notch sensitivity change.

Notch sensitivity was selected as the criterion in that this property can be evaluated and correlated as regards serviceability by means of a simple notch-bend test. By design, the stress concentration value of the applied notch can be made equal that which obtains at the toes of the fillets of the familiar tee-bend specimen. The latter, in turn, represents the most critical joint in weldments.

## THE METHOD

Execution of the concepts given above took form as follows: From the steel to be examined $^3/_8$- by $1^1/_2$- by 8-in. flat bar specimens are taken. These are removed in the manner shown on Fig. 1. The notch design shown on Fig. 2 whose stress concentration value equals that which obtains at the toe of a fillet was developed by means of photoelastic studies. The localized heat treatment was based on mathematical computations, results of Jominy tests and experimentation, and is accomplished by means of high-frequency induction applied by a single turn coil. The results obtained by means of this heating procedure were correlated as regards grain structure development and hardness values with those of the heat-affected zones of multipass arc welds executed under the conditions which were simulated by the high-frequency heat treatment. By employing a simple turn coil the width of the band exposed to the effects of high frequency induction heating is restricted to an approximately $^1/_2$-in. width, the coil being located at mid-length of the 8-in. long flat bar specimens. The single turn coil heats the $^1/_2$-in. wide band from an ambient temperature of 70 to 2150° F. in 49 sec. The geometry and volume of the $^3/_8$- by $1^1/_2$- by 8-in. specimens are sufficient to quench the $^1/_2$-in. wide center portion heated to the above temperature at a rate comparable to that occurring in multipass welds exceeding $^1/_2$ in. in thickness. The above heat treatment, namely, raising the temperature of the center portion of the specimen to 2150° F. in 49 sec., represents welding without preheating and with the ambient air temperature at 70° F. and also with the interpass temperature not over 120° F. To determine whether a welding procedure where no preheat is applied and where the interpass temperature is permitted to sink to 120° F. is applicable to a given steel is performed in the following manner. First, the notch sensitivity of the unwelded base metal, namely in the as-received condition, is determined by deforming a notched-test bar in the adjustable bending jig. This jig has several plungers, whose diameters range from 2-T to 6-T where T = $^3/_8$ in., namely the thickness of the flat bar specimen. The anvil of the jig is separable to accommodate the various size plungers. The notch sensitivity of the unaffected base metal is expressed by the radius of the plunger of the least radius under which it deforms, with the notched side in tension, without developing defects in excess of $^1/_8$ in. in any direction. It is expected that the heat-affected portion of the weldment shall possess no higher degree of notch sensitivity than that of the unaffected base metal. Then it follows that the heat-treated specimens notched in the center of the treated zone should deform without defect development under

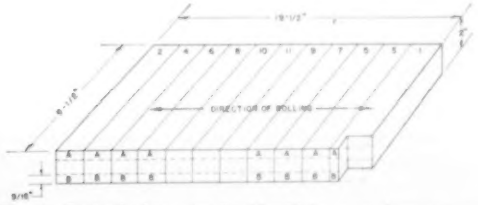

*Fig. 1 Orginal plate, size 2 x 10 x 20 in., cut down to remove hardened faces caused by flame-cutting operation. Chemical sample, $1^1/_2$ x 1 x 2 in.*

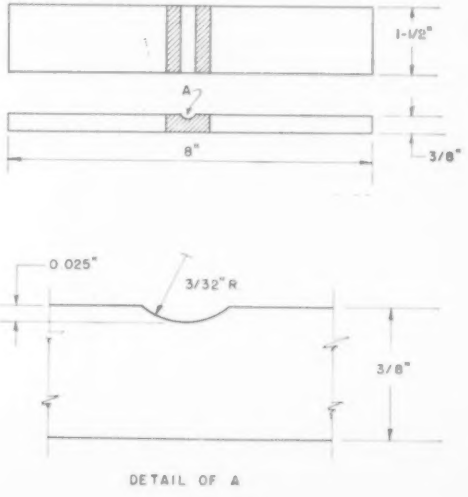


*Figure 2*

the same plunger as the nonheat-treated, notched base metal samples.

In the event the heat-treated specimen fails, indicating increased notch sensitivity, it is then necessary to modify the welding procedure simulated by the high-frequency heat treatment. The modification may consist of pre- and postheating.

To simulate the welding procedure wherein preheating is employed, the sample is preheated in a furnace to the desired level before it is subjected to high-frequency induction heating. To compensate for the preheat, the duration of the high-frequency heating period is reduced in accordance with the chart shown in Fig. 3. This chart was developed empirically. On completion of the high-frequency heating, the specimen is replaced in the furnace and cooled there slowly to room temperature. When preheating is insufficient to counteract the increased notch sensitivity, obviously postheat treatment is indicated.

The applicable postheat treatment level based on the minimum time-temperature combination to reduce the yield point below a specified maximum, usually 3000 psi. for ferritic steels, may be determined independently using the procedure given in reference 1. The simulation of a welding procedure involving both preheat and postheat treatments is carried out as follows: The specimen is preheated to a specified level before it is submitted to the high-frequency heat treatment. On completion of the latter, it is returned to the furnace whose temperature is then raised to the previously determined or arbitrarily chosen postheat treatment level. After having been held at that temperature for the specified length of time, it is cooled with the furnace to room temperature, notched and tested in the bending jig. The postheat temperature level which effectively tempers the heat-affected zone and reduces notch sensitivity to the level of the unaffected base metal may be determined empirically by testing a few specimens post-

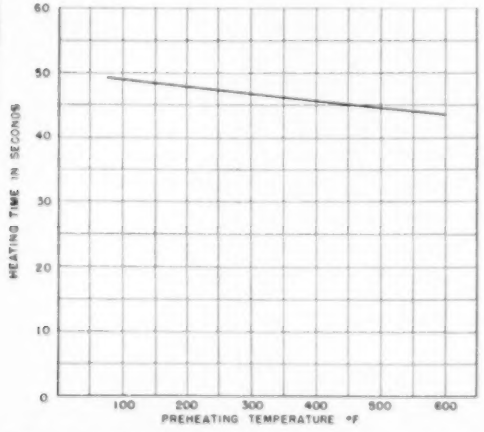


*Fig. 3 The effect of preheating on high-frequency heating of bend bars. Temperature, 2150° F. Specimen, 3/8 x 1 1/2 x 8 in.*

E.E.B. METHOD
for
DETERMINATION OF WELDING PROCEDURES
H.R. SHAFTING
EXPERIMENTAL AUSTENITIC STEEL
AS REC'D 2T BEND RAD.
AS REC'D 4T BEND RAD.
NO PREHEAT HEAT CYCLED NO POSTHEAT 2T BEND RAD.
AS REC'D 8T BEND RAD.
300° PREHEAT HEAT CYCLED NO POSTHEAT 2T BEND RAD.
250° PREHEAT HEAT CYCLED 800° POSTHEAT 8T BEND RAD.
540° PREHEAT HEAT CYCLED 900° POSTHEAT 2T BEND RAD.
250° PREHEAT HEAT CYCLED 500° POSTHEAT 8T BEND RAD
540° PREHEAT HEAT CYCLED 900° POSTHEAT 2T BEND RAD.
500° PREHEAT HEAT CYCLED 1200° POSTHEAT 2T BEND RAD.
300° PREHEAT HEAT CYCLED 1200° POSTHEAT 2T BEND RAD.
250° PREHEAT HEAT CYCLED NO POSTHEAT 8T BEND RAD.
HEAT CYCLED - HEATING A 1/4" WIDE BAND IN CENTER BY HI-FREQUENCY INDUCTION TO 2150° F. AT RATES BELOW
ROOM TEMP. TO 2150° F. IN 49 Sec.
300° PREHEAT - " - - 47 "
500° " " - - 44 "

*Figure 4*

heat treated within the applicable temperature range. However, it is expected that the postheat treatment perform a double function, namely, tempering the heat-affected zone and relieving the residual stress. For many low alloy steels, the temperature which satisfies one of the above requirements also satisfies the other. However, there are steels whose yield point sinks to 3000 psi. at a temperature considerably below that which is required for tempering. An example is the 4/6% chromium–1/2% molybdenum steel whose yield point sinks to 3000 psi. at about 1150° F., but which must be heated to not less than 1350° F. to reduce its notch sensitivity to the normal level. To ascertain whether the temperature level specified to bring about correction of notch sensitivity also satisfies the requirements for stress relieving, it is often advisable to perform the two operations separately.

## ADVANTAGES

The primary advantage of the high-frequency notch-bend test is that after a short period of practice, it can be employed for any complex steel using fewer than 10 specimens, weighing only 12 1/2 lb. to complete the determination of the applicable welding procedure. Two specimens usually suffice to determine the notch sensitivity of the base metal in the as-received condition. Familiarity with the type of steel represented by the material at hand, permits approximation of the preheat level so that two or three additional specimens only are required for this determination. Three more specimens usually are sufficient to determine the postheat

treatment in the event that the minimum temperature has not been previously ascertained on the basis of lowering the yield point to below 3000 psi. In the event that the above preliminary test is performed, fewer than three specimens are needed to determine the applicable postheat treatment temperature. As shown in Fig. 4, a total of six specimens was sufficient to determine the applicable welding procedure for a complex low-alloy steel. The importance of the application of this procedure is fully illustrated by the above example in which less than $5^1/_2$ lb. of steel were employed to complete the procedure. The procedures now employed in industry require the fabrication of several weldments, each weighing upward of 60 lb. The tabulation, Table 1, presents the comparable results obtained from weldments and from specimens wherein the heat-affected zone was produced synthetically by high-frequency heating. The weldments were produced using companion materials from a single plate and employing procedures which parallel those simulated by the high-frequency notch-bend test.

## RESULTS

The data given in Table 1 present a series of wrought and cast Cr-Mo steels intended for high-pressure, high-temperature applications. These results show that the wrought steels tested were not notch sensitive in the as-received condition and that this property was fully restored by the applied pre- and postheat treatment as indicated by the results of the notch-bend test performed for the two types of specimens, wherein the heat-affected zone was produced by either welding or high-frequency heating.

***Table 1***

| MATERIAL "AS RECEIVED" | | | HIGH FREQUENCY NOTCHED BEND APPLIED | | | | WELDED PLATES |
|---|---|---|---|---|---|---|---|
| LOW ALLOY STEEL | NOTCHED SENSITIVITY | HARDNESS | PREHEAT (°F.) | POSTHEAT (°F.) | NOTCHED SENSITIVITY | HARDNESS H.F. HEATED AREA | HARDNESS HEAT AFFECTED AREA |
| WROUGHT 1/2Cr-1/2Mo | 27 | 126 | 550 | 1275 To 1300 | 27 | 183 | 158 |
| WROUGHT 1Cr-1/2Mo | 27 | 140 | 400 To 500 | 1275 To 1300 | 27 | 225 | 166 |
| WROUGHT 2¼Cr-1Mo | 27 | 137 | 400 To 600 | 1300 | 27 | 295 | 170 |
| WROUGH 4-6Cr-1/2Mo | 27 | 170 | 600 | 1300 DRAW 900 | 27 | 170 | 195 |
| CAST 1/2Cr-1/2Mo | 27 | 159 | 500 To 900 | 1275 To 1300 | 27 | 179 | 159 |
| CAST 0.27%C-0.51%Mo | 37 | 191K | 300 | NONE | 37 | 263K | 255K |
| CAST 0.28%C-0.52%Mo | 47 | 205K | 300 | NONE | 47 | 295K | 305K |
| CAST 0.33%C-0.55%Mo | 37 | 215K | 500 | 1200 | 37 | 285K | 230K |

K = KNOOP HARDNESS NUMBER
ALL OTHERS ARE BRINELL CONVERTED FROM ROCKWELL B&C SCALES

The cast materials tested showed a tendency toward notch sensitivity in the as-received condition for those wherein the carbon content exceeded 0.25%, with the maximum sensitivity noted in the 0.28 C material. It is noted, however, that the degree of notch sensitivity did not increase either in the heat-affected zones in the welded samples or in those wherein it was produced synthetically although a considerable increase in hardness is noted for the heat-affected portions of the latter specimens.

The hardness values obtained for the heat-affected zones produced by welding and synthetically are, in general, in good agreement though those for synthetically treated samples are somewhat higher than the averages given for the welded materials. This apparent discrepancy is readily understood in view of the variations noted in a hardness exploration of a weld section. Hardness readings for a weld section show a considerable range in that they include, inadvertently, portions of the transition zone. Also, the hardness values may vary from pass to pass as the cooling rate changes with varying rates of progression or other changes in the power input rate. Thus, the averages computed for the hardness of the heat-affected zones of welds usually represent the means of a considerable range which includes lower values than those obtaining within the wide band of the synthetically produced heat-affected zones. In taking the hardness reading by the Knoop indentor there is better control as regards the location of the indentations and since the test is performed for etched specimens, each selected location is first viewed on the 100 × power microscope, thus the operator can readily avoid taking readings within the transition zone. It is therefore noted that the Knoop readings for the two types of specimens examined are in close agreement. It is also noted that the degree of notch sensitivity of two of the cast materials tested remained unchanged subsequent to exposure to the thermocycle of welding, either actual or simulated, without the benefit of postheat treatment. Applying stress relief treatment at the 1200–1300° F. level to these cast metals did not reduce the notch sensitivity level below that given for the as-received condition.

The principal drawback of this procedure is the requirement for the costly 10 to 15 kw. capacity high-frequency generator. However, it has been demonstrated that the savings obtained by elimination of welding tests, reimburse the cost of the high-frequency generator in a few applications. In addition, laboratories and production departments readily find other work for a high-frequency generator as the power source for surface hardening, brazing and other heat treatments. To render the procedure more attractive to industry, tests are being performed currently to adapt inexpensive 60-cycle, single-phase transformers to produce, by means of resistance heating, the metallurgical effects now obtained by high-frequency induction heating.

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# Weld Embrittlement in Chromium Stainless Steels

***Water quenching or air cooling certain types of stainless irons from above 2200° produces embrittlement which is not reliably detected by hardness measurement. It may be removed by post annealing***

*by Helmut Thielsch*

**Abstract**

A new type of embrittlement occurring in low-carbon high-chromium irons has been investigated using high-temperature furnace quench tests, induction heating techniques and weld tests.

Water quenching or air cooling Types 405, modified 410 (less than 0.08% carbon) and 430 stainless irons from temperatures above 2200 to 2300° F. will produce in them a rather abrupt embrittlement and increase in hardness. This change in mechanical properties appears to occur at temperatures at which all the austenite and carbides have been dissolved in delta-ferrite. Embrittlement seems to accompany severe grain growth, but a large grain size alone will not account for it.

Hardness values alone do not give a true (relative) indication of the other mechanical properties of these stainless irons. Thus, while two specimens of the same alloy, quenched from different elevated temperatures, exhibited identical hardness values, the elongation was found to vary by as much as 20% (in 2 in.) and the Charpy impact values by 20 to 25 ft.-lb.

With exception of the excessive grain growth, the detrimental effects of overheating may be removed by annealing between 1350 and 1450° F. Thus, multibead weld deposits will be superior to single bead welds. However, for improving properties, postannealing is far superior to any change in welding technique and should be employed wherever a restoration of the ductile properties of the steel is of major importance.

## INTRODUCTION

IT IS well known that the straight-chromium stainless steels are not welded as easily as the austenitic chromium-nickel grades. For example, Jennings,[1] Zeyen[2] and Miller[3] have reported that chromium steels ranging in composition between approximately 12 and 17.5% chromium, and welded with similar type welding rods, failed in the as-welded condition on bending as little as 14 to 33°. This, obviously, is characteristic of highly brittle behavior. However, subsequent thermal "stress-relieving" treatments between 1300 and 1450° F. will restore the steel to satisfactory ductility, giving bend angles as high as 180°.

Improved results are obtained by using austenitic welding electrodes. However, here some embrittlement can still be noted in the heat-affected zone of the parent metal and often welds will fracture in a highly brittle fashion. To some extent this will depend upon the welding technique, that is the temperature of overheating in the embrittling range. Thus gas welding, by its nature, will develop a deeper heat-affected zone than electric arc welding.[5] This highly detrimental embrittlement of the fully and partially ferritic chromium steels occurs on heating at temperatures above 2200 to 2300° F. By depositing several beads, the possible stress-relieving effect may reduce somewhat the degree of embrittlement.

These unfavorable results introduce a conflict with impressions gained from Section 7 of the "Interpretations of the A.S.M.E. Boiler Code," Case 896, approved October 25, 1948.* This section states that stress-relieving treatments may be omitted on "Grade O material and Grade A with 0.08 maximum carbon welded with austenitic electrodes." A.S.M.E. Grades O and A correspond to the A.I.S.I. Types 405 and 410, respectively.

Contrary to the above specifications, considerable trouble has been experienced in many Type 405 (Grade O) and low-carbon 410 (the "modified" type) (Grade A) welded assemblies which have not been stress relieved. This is true also for the Type 430 compositions which, however, are not covered in the above specification. It should be remembered that although Types 405 and 430 stainless irons are essentially ferritic in nature, they are capable of exhibiting brittleness to a degree surpassing even that of their martensitic, high carbon Type 410 (0.08–0.15% C) counterpart.

Because of the apparently critical nature of the high-temperature embrittlement resulting from welding and possible overheating a detailed investigation was undertaken in the Research Laboratories of the Lukens Steel Co. to study the effects played by various heat

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* A copy may be obtained from the A.S.M.E. Boiler Code Committee, American Society of Mechanical Engineers, 29 W. 39th St., New York 18, N. Y.

treatments on the mechanical properties and the microstructure of these steels.

## ALLOYS STUDIED

Four major types were studied for which the composition ranges are given in Table 1.

**Table 1—Type Designations and Compositions of Major Martensitic-Ferritic Stainless Irons**

| *Type* | *C, Max.* | *Mn, Max.* | *Si, Max.* | *Cr* | *Al* |
|---|---|---|---|---|---|
| 405 | 0.08 | 1.00 | 1.00 | 11.50–13.50 | 0.10–0.30 |
| 410 | 0.15 | 1.00 | 1.00 | 11.50–13.50 | ... |
| 410 (modified) | 0.08 | 1.00 | 1.00 | 11.50–13.50 | ... |
| 430 | 0.12 | 1.00 | 1.00 | 14.00–18.00 | ... |

Sulphur 0.03% max. Phosphorus 0.04% max.

The actual compositions of the alloys discussed in this article are given in Table 2.

## EXPERIMENTAL PROCEDURE

The experimental procedure was divided into three major sections. These were (1) furnace heat treatments, (2) induction heating tests and (3) tests on weld deposits.

The furnace heat treatments were designed to show quantitatively the effects played by quenching different alloys from various elevated temperatures. These tests should give an idea as to how heating to weld temperatures may alter the physical properties of annealed specimens. To gain an understanding of the whole elevated temperature range, the specimens were heated in a globar furnace at temperatures between 1500 and 2500° F., varied in steps of 100° F. To equalize the structure of the specimens as well as possible, a preheat treatment was employed consisting of a 20-hr. anneal at 1450° F.

All the major mechanical properties were of interest. Thus, three types of specimens had to be heat treated.

Hardness values were obtained from blocks measuring about 1 x 1 x $^1/_8$ to $^3/_{16}$ in. Rockwell "B" or "C" determinations were made. Ten readings were taken on each specimen to $^1/_2$ point Rockwell. Moreover, the indenter was checked frequently on a standard test block. From the experiments it is felt that an accuracy of better than one point Rockwell was obtained. The averaged readings were converted to Brinell hardness numbers. This is practiced by most investigators on these stainless alloys, and allows thus better comparison to the data reported in the literature.

Charpy keyhole impact specimens were milled down to a thickness of $^1/_2$ in., heat treated and quenched and finally milled and ground to their standard dimensions.

The tensile tension specimens were heat treated in the form of 1-in. square bars. After quenching these were machined down to standard dimensions. The surface of these two types of specimens was checked also by hardness readings.

A rapid water quench was obtained by placing the quench tank immediately under the furnace door. The specimens were dropped into the tank and agitated.

To simulate the short heating cycle of welding, a number of specimens were heated under carefully controlled conditions in an induction furnace. The tests were conducted at Lehigh University using a Lepel High-Frequency Unit having a rating of 30 k.w. The induction coil consisted of 16 turns of $^1/_4$-in. water-cooled copper tubing flattened to $^3/_{16}$ in. The inside area of the coil was about $^3/_8$ x 2 in. The test specimens measured 1 x 3 x $^1/_8$ in. They were placed about 1 in. deep into the induction coil—the other 2 in. remaining in air. Platinum–platinum-rhodium thermocouple wires were spot welded about $^1/_8$ in. apart to the end of the specimens inside the induction coil, using a small condenser discharge spot welder. The other ends of the thermocouple wires were connected to a Speedomax controller, which was adapted with a sensitive circuit breaker. This cut off the induction furnace immediately when the specimen reached a certain set maximum temperature.[4] Variations were made in the maximum temperature to which the specimens were heated and in the time cycle by changing the power input to the induction coil. After heating, the test pieces either were air cooled or were water quenched into a bucket placed below the coil.

Arc weld tests were made in two groups. First, a narrow $^1/_4$-in. wide bead of 25/20 weld metal (25% Cr–20% Ni) was laid on a series of 1 in. wide 405–410 specimens. The specimens were then investigated for hardness and microstructure. Moreover, a number of standard weld bend tests were prepared using, again,

**Table 2—Analyses of Alloys Discussed**

| *Alloy No.* | *C* | *Mn* | *Si* | *P* | *S* | *Ni* | *Cr* | *Al* | *Type* |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.071 | 0.44 | 0.15 | 0.030 | 0.013 | 0.43 | 12.59 | 0.15 | 405 |
| 3 | 0.045 | 0.40 | 0.27 | 0.005 | 0.008 | 0.31 | 12.23 | 0.26 | 405 |
| 7 | 0.08 | 0.35 | 0.36 | 0.030 | 0.014 | 0.29 | 13.40 | 0.02 | M410 |
| 19 | 0.11 | 0.37 | 0.23 | 0.024 | 0.015 | 0.33 | 12.71 | 0.03 | 410 |
| 31 | 0.09 | 0.29 | 0.51 | 0.021 | 0.015 | 0.32 | 12.87 | 0.17 | 405 |
| 37 | 0.068 | 0.29 | 0.46 | 0.014 | 0.012 | 0.28 | 13.14 | 0.17 | 405 |
| 44 | 0.041 | 0.48 | 0.39 | 0.020 | 0.028 | 0.35 | 14.14 | 0.26 | 405 off analysis |
| 49 | 0.065 | 0.46 | 0.33 | 0.019 | 0.025 | 0.39 | 12.74 | 0.03 | M410 |
| 53 | 0.062 | 0.50 | 0.28 | 0.017 | 0.028 | 0.46 | 12.41 | 0.02 | M410 |
| 57 | 0.088 | 0.42 | 0.45 | 0.021 | 0.017 | 0.34 | 15.44 | 0.03 | 430 |
| 73 | 0.11 | 0.45 | 0.46 | 0.029 | 0.010 | 0.39 | 12.64 | 0.02 | 410 |
| 81 | 0.067 | 0.46 | 0.37 | 0.027 | 0.016 | 0.33 | 12.91 | 0.02 | M410 |

25/20 welding rods. On some of these the depth of the welding groove and the rate of travel of the welding rod were varied.

## RESULTS OF FURNACE HEAT TREATMENTS

In these alloys chromium, carbon and aluminum are the three most important elements in determining the mechanical and structural properties. For chromium and carbon this is evident from Fig. 1 in which are shown the effects of quenching temperatures on the Brinell hardness values of three typical alloys. The 1- x 1- x $^{1}/_{8}$- to $^{3}/_{16}$-in. test blocks were heated at the respective temperatures for 20 min. before quenching into water. Similarly, Fig. 2 shows the effects of varying amounts of aluminum.

The curves demonstrate clearly how carbon will increase the maximum (martensitic) hardness values, while aluminum will counteract its effects, tending to stabilize the ferrite. The maximum hardness, occurring at 1800–1900° F., corresponds to the maximum extent of the gamma loop, Fig. 3, or, in other words, the maximum amount of austenite which, on cooling, transforms into martensite below 800–900° F.

Above 1800° F. (delta) ferrite will form from austenite, which will leave less austenite (or, after cooling, less martensite). Thus, hardness values will decrease.

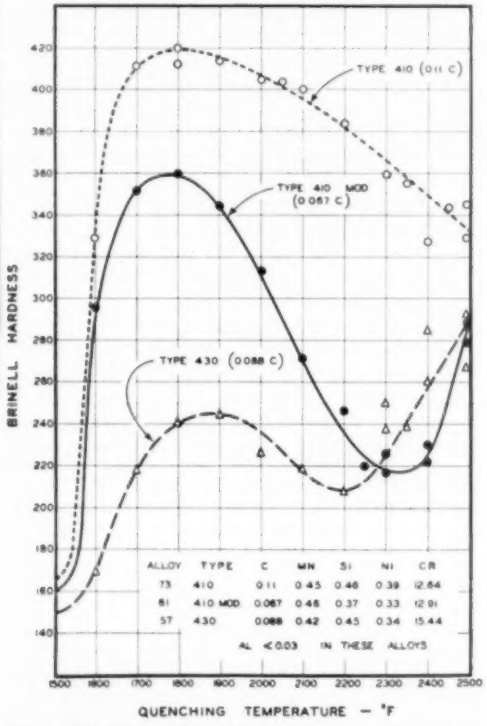

BRINELL HARDNESS
TYPE 410 (0.11 C)
TYPE 410 MOD (0.067 C)
TYPE 430 (0.088 C)
ALLOY TYPE C MN SI NI CR
73 410 0.11 0.45 0.48 0.38 12.64
51 410 MOD 0.067 0.46 0.37 0.33 12.91
57 430 0.088 0.42 0.45 0.34 15.44
AL <0.03 IN THESE ALLOYS
QUENCHING TEMPERATURE — °F

*Fig. 1 The effects of quenching temperature on hardness values of typical type 410 and 430 stainless irons*

With the exception of the Type 410 stainless steels containing more than 0.08% carbon, the curves assume a minimum above 2200° F. after which they increase

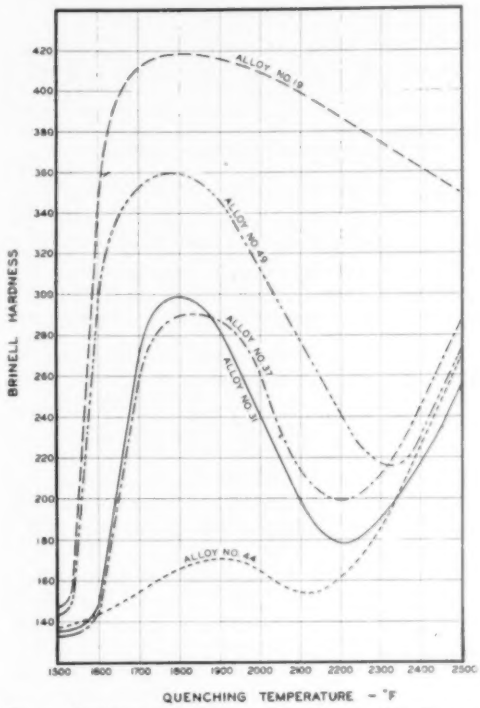



*Fig. 2 Hardness values of a series of type 405–410 chromium irons quenched into water from elevated temperatures*

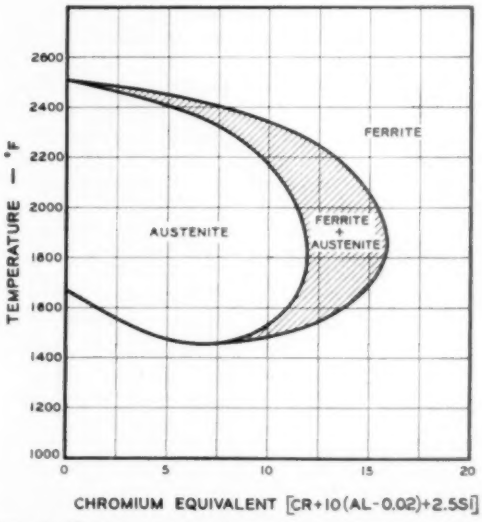



*Fig. 3 The "gamma loop" as influenced by chromium, aluminum and silicon in stainless irons containing 0.05% carbon*

Table 3—Effects of Annealing for 20 Hr. at 1350° F. on Modified Type 410 Alloy (No. 53) Quenched from Temperatures between 1500 and 2500° F.

| Water quenched from, °F. | As-quenched: Hardness Brinell | As-quenched: Tensile strength, psi. | As-quenched: Elongation % in 2 in. | As-quenched: Charpy impact, ft.-lb. | Quenched and annealed 20 hr. at 1350° F.: Hardness Brinell | Quenched and annealed 20 hr. at 1350° F.: Tensile strength, psi. | Quenched and annealed 20 hr. at 1350° F.: Elongation % in 2 in. | Quenched and annealed 20 hr. at 1350° F.: Charpy impact ft.-lb. |
|---|---|---|---|---|---|---|---|---|
| 1500 | 143 | 82,600 | 25.7 | 40 | 142 | 84,200 | 25.8 | 41 |
| 1600 | 344 | 137,100 | 14.9 | 22 | 147 | 84,700 | 25.2 | 38 |
| 1700 | 378 | 169,200 | 11.5 | 19 | 157 | 85,800 | 25.8 | 36 |
| 1800 | 380 | 185,300 | 11.7 | 21 | 163 | 86,200 | 24.2 | 35 |
| 1900 | 377 | 184,900 | 11.8 | 19 | 162 | 85,700 | 24.9 | 40 |
| 2000 | 338 | 177,500 | 11.7 | 15 | 160 | 82,800 | 25.3 | 36 |
| 2100 | 311 | 173,700 | 11.5 | 16 | 158 | 83,200 | 26.1 | 37 |
| 2200 | 266 | 171,000 | 10.2 | 10 | 157 | 81,300 | 25.0 | 42 |
| 2300 | 222 | 161,000 | 6.3 | 6 | 155 | 79,200 | 25.3 | 44 |
| 2400 | 216 | 152,500 | 3.9 | 5 | 155 | 75,800 | 25.8 | 46 |
| 2500 | 301 | 154,800 | 3.9 | 4 | 162 | 66,400 | 27.3 | 49 |

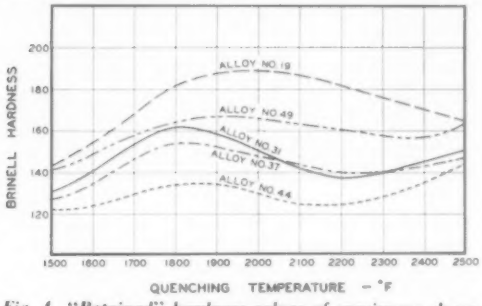



*Fig. 4 "Retained" hardness values of specimens shown in Fig. 2, but after annealing for 20 hr. at 1350° F.*

again. Although the results are plotted only up to 2500° F., still higher hardness values can be obtained when quenching the specimens from temperatures near the melting point of the alloy; that is, above 2700° F. The other mechanical properties also are affected adversely when the specimens are quenched from temperatures above 2200° F.

Examination of the macro- and microstructures reveals that the high-temperature embrittlement occurs simultaneously with severe grain growth. However, the large grain size alone is not responsible for the adverse properties. Unfortunately, this has not been realized by a number of authors. It becomes apparent when a series of specimens quenched from high temperatures is subsequently subjected to an anneal consisting of holding for 20 hr. at 1350° F. The normal mechanical properties of the stainless steels are almost completely recovered, as is shown in Table 3. Obviously, the severe grain growth should decrease the properties somewhat. Microscopically the only apparent change following the 1350° F. anneal consists of a softening of the grain boundary martensite into sorbite.* This also cannot be the reason for the embrittlement, as the greatest amount of martensite exists at around 1800° F.

Scheil pointed out earlier[6] that the structure and mechanical properties resulting from certain heat treatments will depend upon the previous thermal history (pretreatments) of the steel. This is most clearly apparent in hardness surveys.

In Fig. 2 were shown the Brinell hardness values obtained on a number of alloys which had been quenched from temperatures between 1500 and 2500° F. Annealing these same quenched specimens for 20 hr. at

* That is carbides distributed in ferrite.

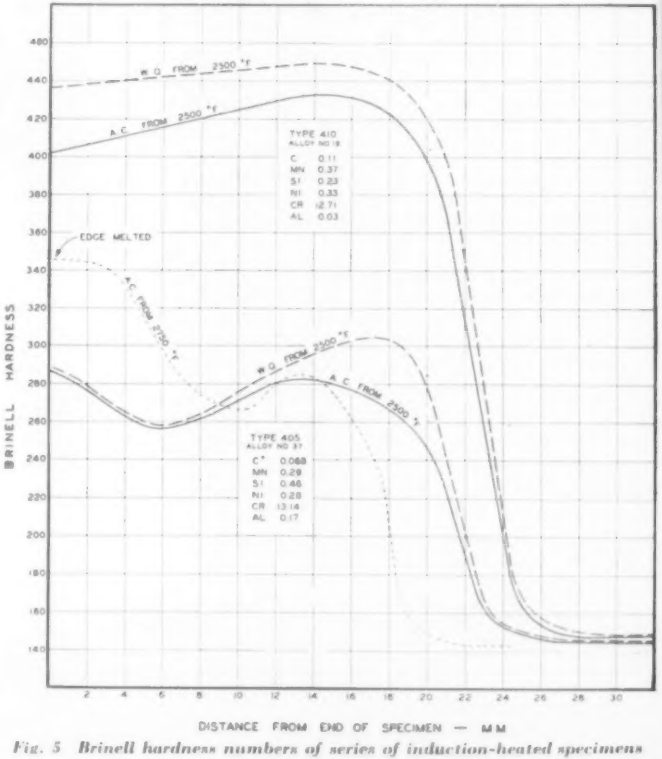



*Fig. 5 Brinell hardness numbers of series of induction-heated specimens*

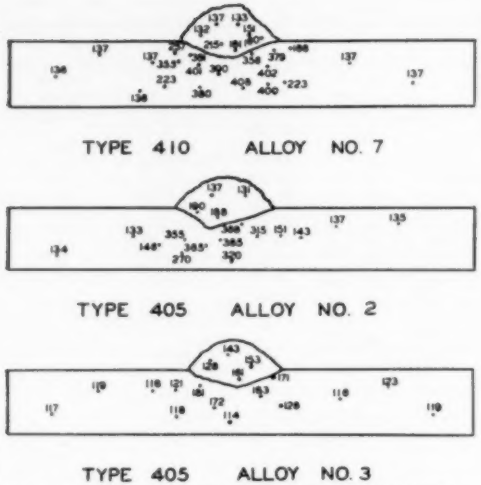



*Fig. 6 Hardness survey on three different welded stainless chromium irons*

1350° F. reduced the hardness values to those plotted in Fig. 4. The trend of the curves has not changed. On the other hand, the microstructure of the annealed specimens consists now of ferrite and sorbite.

## RESULTS OF INDUCTION HEATING

In the furnace heat treatments about 2 to 3 min. were necessary to bring up to 2200 to 2500° F. the little test blocks measuring 1 x 1 x 1/8 in. By induction heating these same temperatures were reached in about 4 to 9 sec. depending upon the power input into the induction coil. It is evident that the induction heating tests permit considerably better comparison than furnace heat treatments do with results obtained in the welding of these specimens.

The results of significance are plotted in Fig. 5. The distance in millimeters was measured from the end which was heated to maximum temperatures and onto which the controlling thermocouples had been spot welded. Thus the distance may be correlated roughly to temperatures. For the set of specimens heated to 2500° F. a distance from the thermocouple wires of 6 mm. corresponds to about 2200° F., 12 mm. to 2000° F., 18 mm. to 1800° F. and 24 mm. to 1600° F. It is apparent now that the trend exhibited by these curves is similar to the results plotted in Fig. 2 from the furnace heat-treatment quench tests.

In the Type 410 stainless iron (No. 19), the hardness values of the water-quenched and air-cooled specimens were higher ("superhardness") than those obtained on the same specimens heat treated in the furnace. This demonstrates the effect of time upon the homogenization of these alloys. Moreover, these tests show also the role played by the cooling rate. Thus, the slower rates due to the air cooling will allow some of the austenite to transform into ferrite, before the martensite transformation range is reached at temperatures about 800–900° F. In addition, the quenching stresses will be less severe in the air-cooled than in the water-quenched specimens.

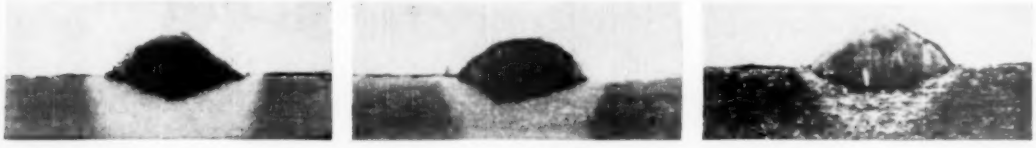
Similarly, the Type 405 alloy (No. 37) showed higher hardness values on the quenched specimen in comparison to its furnace heat-treated counterpart. The air-cooled section, due to its slower cooling rate, gives again lower Brinell readings than the water-quenched specimen. The minimum hardness values are less pronounced. This may be explained by the lack of homogenization and the relatively steep temperature gradient.

One of the (405) specimens was heated to its melting point, giving a maximum hardness of about 345 Brinell. This is in good agreement with extrapolations to 2750° F. of the hardness values obtained in the furnace heat treatment (Fig. 2).

By varying the power input into the induction coil, the rate of heating of the test specimens may be altered considerably. Some experiments were made indicating a slight lowering in the hardness values. Unfortunately, the number of such tests made was insufficient, not allowing, therefore, the formulation of conclusions in regard to heating rates. However, this testing approach, if developed, may give significant results relative to welding techniques, travel speed, depth of deposit relative to section size, etc.

## RESULTS OF WELDING TESTS

As in the induction heating tests, the specimens on which a narrow bead of 25/20 weld metal had been deposited showed somewhat higher hardness values in comparison to the results obtained from the furnace heat-treatment quenching tests. Again the degree of "superhardness" is greater in alloys having higher carbon contents.



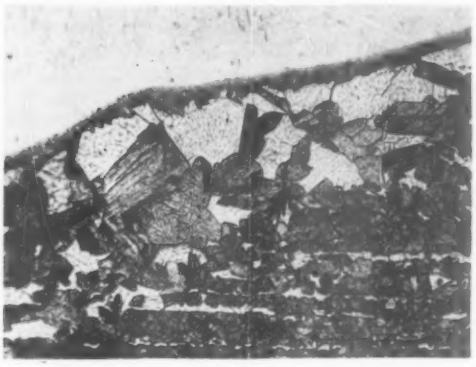
Type 410. Alloy No. 7. C, 0.08; Mn, 0.35; Si, 0.36; Ni, 0.29; Cr, 13.40; Al, 0.02

Type 405. Alloy No. 2. C, 0.071; Mn, 0.44; Si, 0.15; Ni, 0.43; Cr, 12.59; Al, 0.15

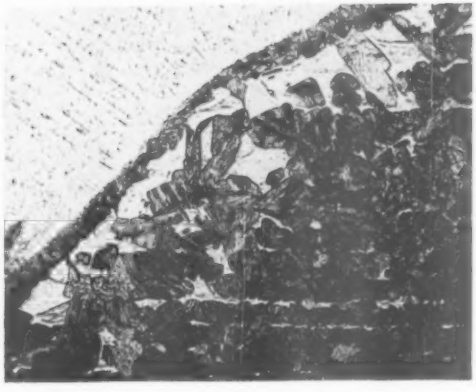
Type 405. Alloy No. 3. C, 0.045; Mn, 0.40; Si, 0.27; Ni, 0.31; Cr, 12.23; Al, 0.26

*Fig. 7 Macrographs of weld specimens shown in Fig. 6. (All 5 ×)*

The results of hardness surveys on three different welded stainless irons are shown in Fig. 6. The compositions of these alloys and macrographs of the weld sections are given in Fig. 7. The depth of the (martensite) heat-affected zone is indicated clearly and compares well with the hardness reading in Fig. 6. Photomicrographs of the same alloys showing the weld metal interface are reproduced in Fig. 8. From these it is again apparent that Alloy No. 3, having the highest aluminum content, experiences the greatest degree of grain growth. It should be realized that most welding processes using electrodes wider than if $^1/_4$-in. electrodes were used would produce a wider heat-affected zone.



Alloy No. 7



Alloy No. 2

Alloy No. 3

*Fig. 8 Microsections of weld-metal interface of specimens shown in Figs. 6 and 7 (All 250×)*

No quantitative studies were conducted on welded sections in bend tests. However, surveying tests were made on Type 405 and some Type 410 specimens by depositing different type beads varying from heavy single passes to thinner multiple passes. Most of the specimens which had received a heavy single deposit seemed to fracture even with slight amounts of bending. On the other hand, the specimens which had been given several thin passes showed much improved bending properties. Moreover, a fast rate of travel of the rod gave superior results compared to slower speeds. With faster rates not enough of the section may be heated to temperatures sufficiently high to cause the high-temperature embrittlement. By making several passes with the welding rod, a tempering effect, or even temperatures causing martensite formation, may be produced in the welding zone. As it has been shown, even this martensite has properties superior to those of sections quenched from the high-temperature embrittlement range.

However, for best results weld sections should be annealed after welding. Only in this way may the normal ductile properties of the material be restored. This is especially true for clad assemblies between these chromium irons and the usual backing steel. In these, some carbon is picked up in the bond zone of the stainless iron increasing the seriousness of martensite formation and high-temperature embrittlement. Yet, if the problems associated with this embrittlement are understood, and if controlled welding procedures are employed, annealing may be dispensed with in applications not subjected to severe service stresses.

## CONCLUSIONS

The causes of this high-temperature embrittlement are not yet quite clear. Embrittlement seems to accompany severe grain growth although a large grain size alone will not account for the embrittlement. As this severe grain growth cannot occur unless the austenite and the carbides (also other possible compound particles) have been dissolved, its association to embrittlement is apparent. Thus carbide stabilizers, raising the temperature at which these particles go into solution, seem to increase proportionally the minimum temperature at which embrittlement can be noted.[7] Further studies should clear this up.

Of greatest practical significance is the fact that this type of embrittlement does occur in the ferritic grades and that hardness values alone do not give a true indication of the other mechanical properties. The accept-

ance of welds, therefore, cannot be based on hardness values alone.

Annealing between 1350 and 1450° F. will remove most of the effects of the high-temperature embrittlement. In part this may be accomplished by depositing multibeads. However, postannealing is far superior and should be employed wherever a restoration of the ductile properties of the steel is of major importance.


### ACKNOWLEDGMENT

The author wishes to thank Thomas T. Watson, Director of Research of the Lukens Steel Co., for his encouraging and suggestive interest in this investigation. Moreover, the kind assistance of Dr. J. Libsch, at Lehigh University, made the induction tests possible. Permission of the Lukens Steel Co. allowing publication of this paper is appreciated greatly.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# Strain Aging in Welding Structural Steel

***Discussion by R. E. Lorentz, Jr.***

In the present paper covering rimmed steel as in the one given here last year and which covered semikilled steel, the authors are to be congratulated for their thorough analysis and comprehensive data. In each of these papers the weld metal was the E6010 grade, which grade is widely used because of its excellent physical properties and its adaptability to out-of-position welding.

Summarizing the results of these two papers, it would appear that any embrittling effect due to the small amounts of strain ordinarily encountered in weldments combined with aging at room temperature and at elevated temperatures encountered in service would be small. Although the transition temperature of strained rimmed steel is raised somewhat by aging, it is practically the same as that of the as-rolled and stress-relieved rimmed steel. The primary concern seems to be the transition temperature of rimmed steel being at room temperature and above. Although the transition temperature of thermally stress-relieved weld metal in rimmed steel is higher than the thermally stress-relieved weld in semikilled steel, the difference is again relatively small.

If transition temperatures were determined for the heat-affected zone of the base metal, it might be found that this area is a critical one. Strain-aging tests, especially if the base metal heat-affected zone is critical, might be worth while to make on steel welded by the one-pass or two-pass submerged arc process. Since this process is widely used and since this process results in deposited weld metal with large columnar grains, such a study might prove interesting. Since this process as well as the other shielded arc processes gives good protection from the atmosphere during welding, the difference, if any, may be due only to the larger grain structure.

A few minor points on which the writer would appreciate clarification are:

1. Was a particular interpass temperature used in welding and if so, what?

2. Why did straining significantly harden killed steel and weld metal deposited in killed steel (Figs. 8 and 9, THE WELDING JOURNAL, **27** (9), 441-s to 447-s (1948) and not harden rimmed steel and weld metal deposited in rimmed steel (Figs. 3 and 4, *Ibid.*, **28** (9) 397-s to 404-s (1949)?

3. For room temperature aging tests, were special techniques used for keeping specimens below room temperature during preparation?

4. Were tension tests in the blue heat region made for the weld metal, the rimmed steel and the semikilled steel, and, if so, did they indicate a difference between the rimmed steel and the killed materials?

There seems to be more or less general opinion that nitrogen in the metal leads to aging. A few analyses for nitrogen made by the writer's company of E6010 deposited metal showed less than 0.01% nitrogen. Several analyses of E6020 and E7020 deposited metals showed a minimum of 0.011% nitrogen and a maximum of 0.072% nitrogen with an average of 0.029% nitrogen (average of 18 determinations). All of these grades of deposited metal have a carbon analysis of 0.07 to 0.12% and a silicon analysis of 0.08 to 0.28%.

The authors in these two papers have given data which throw considerable light on questions many persons have been wondering about for some years. Authoritative data as given here is much appreciated by those interested in the multitudinous technical aspects of welding.


**R. E. Lorentz, Jr.**, Metallurgist, Combustion Engineering-Superheater, Inc., Chattanooga, Tenn.


Paper by W. H. Bruckner and S. W. Sandberg published in THE WELDING JOURNAL, **28** (9), Research Suppl., 397-s to 404-s (1949).

(1) THE WELDING JOURNAL **27** (9), Research Suppl., 441-s to 447-s (1948).

## *Discussion by Wells E. Ellis*

In my opinion the most significant part of this study of strain aging was the fact that the authors chose a rimmed steel of well-known susceptibility to strain aging and still the weld metal was not embrittled by cold work in excess of 8%.

The authors state that, "quench aging may have been responsible" for the increase in hardness shown by the mechanically stress-relieved specimens in Fig. 5. Quench aging and strain aging are additive with respect to increasing hardness. The plates *G* and *H* of Fig. 5 exhibited a continuous increase in hardness with time at room temperature, in spite of the decrease in hardness shown by the as-welded specimen. This would suggest that the increase in hardness due to strain aging has more than compensated for the decreasing hardness after quench aging. Data have been reported which showed that the rise in hardness caused by strain aging was still increasing after aging one year at room temperature.

The results of this paper together with the previous paper by Bruckner and Ellis[1] have indicated that fine-grained, recrystallized E6010 weld metal was insensitive to strain aging regardless of whether the plate material showed strain aging. The more complex portion of the welded joint, the heat-affected zone, remains to be investigated. The point I would like to emphasize is that of prior microstructure. The work of Enlund[2] in Sweden places the following microstructures in order of increasing susceptibility to strain aging: (1) quenched and tempered, (2) normalized and (3) furnace cooled. Thus a single pass weld of E6010 type, for example, would be expected to be more susceptible to strain aging than a fully refined multiple pass weld.

The authors are to be congratulated for their thorough study of strain aging as affecting weldability.

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## *Authors' Reply*

The investigation represented by the two A.W.S. papers bearing the same title was mainly concerned with the strain aging of the weld metal rather than the welded joint. It was necessary to investigate the behavior of the parent metal to determine control values and to discover how much of the strain-aging sensitivity of the base metal had been carried over into the weld metal. Both Lorentz and Ellis and others during oral discussion of our paper pointed to the heat-affected base metal as possibly the most critical portion of the weld joint from the standpoint of sensitivity to strain aging. The authors agree with the discussors regarding the possible greater sensitivity of on heat-affected base metal and they also share their hope that research on this phase of the problem will soon be under way. The authors believe their own contribution showing that little strain-aging sensitivity is ascribable to the recrystallized weld metal when coupled with the work done by A. A. Flanigan, who shows a high sensitivity to strain aging in the columnar weld metal gives a good, over-all view of what to expect of the weld-deposited metal. A study of the heat-affected base metal would complement the above studies and would complete the study of the welded joint.

In regard to specific questions raised by Mr. Lorentz it can be noted that interpass temperature was approximately 130° F. since the plate was allowed to cool almost to room temperature before the next run of weld metal was placed. The question regarding the different strain-hardening characteristics of the semi-killed and the rimmed steel points to an interesting problem on which there is insufficient data at present to provide a clear answer. It appears that all hardness tests of plastically deformed metals may be in error since the residual elastic stresses in the region of the hardness indent may be either additive or of opposite sign in relation to the stress causing the hardness indentation. We were mainly concerned with a change in the base hardness after straining as an indication of aging.

The only specimens which were stored in a refrigerator at lower than room temperature were those which were artificially aged at temperature above the room. For these specimens it was noted that aging took place almost as rapidly as for those which were aged at room temperature after straining. No tension tests were made in the blue heat region.

We appreciate the interest which was manifested in the subject of strain aging by the written and oral discussion when the paper was presented. We wish to thank those who discussed the paper for their interest and their efforts in adding to the existing information.


**Wells E. Ellis**, Research Metallurgist, The Timken Roller Bearing Co., Canton, Ohio.

# Seam Welding Monel Metal to Steel

***Seam welding of Monel to steel requires a braze type of weld with fusion only in the Monel. Optimum welding conditions are indicated***

*by Ernest F. Nippes, Allan R. Pfluger and Gerald M. Slaughter*

**Abstract**

A study was made of the resistance seam welding of Monel to low-carbon steel in the 0.062-in. gage. It was found that for the weld times investigated fusion of both the Monel and steel resulted in a heterogeneous weld nugget and led to porosity and cracking in the weld zone. To avoid the above porosity and cracking, seam welds of Monel to steel were made with fusion occurring only in the Monel. The optimum conditions for producing these "braze" type welds were established. The strengths of welds made by this method exceeded those of seam welds of steel to steel. The pillow test was found to be a valuable aid in determining the strength and pressure-tightness of seam welds.

## INTRODUCTION

THE welding of dissimilar metals brings up many problems which are not encountered in welding two identical metals. These difficulties may arise from differences in physical properties such as lattice structures, melting points, thermal conductivities, electrical resistivities, thermal expansion characteristics and specific heats. Of possibly even greater importance are the difficulties stemming from differences in metallurgical characteristics. Alloying, with the formation of solid solutions or intermetallic compounds, may materially affect the properties of the welded bond.

The joining of dissimilar metals may be achieved by various welding methods such as fusion welding, brazing, soldering or electric resistance welding. In the present investigation, only the resistance welding method was studied.

In a Review of the Literature on the Welding of Dissimilar Metals[1] the following conditions were found necessary in order to obtain a satisfactory resistance-welded joint between two dissimilar metals:[2]

1. Avoid the formation of intermetallic compounds which are as a rule brittle and produce cracks in the joint. This condition is equivalent to reducing as much as possible the amount of mutual alloying. Several means of achieving this aim which tend to limit the rate and degree of diffusion are:
   - (*a*) Reducing the time and extent of preheating to a minimum (example, condenser discharge welding, pulsating welding).
   - (*b*) Avoiding the formation of a molten slug either entirely or at least in one of the two metals.
   - (*c*) Interposition of a third metal.
   - (*d*) In pressure resistance welding (or flash welding) by extruding all of the brittle intermetallic compound by merely pushing up the weld.
2. Reduce the magnitude and/or the rate of thermal and residual stresses produced by the dissimilarity of thermal coefficients. This is accomplished either by selecting proper chemical composition of both dissimilar metals or better by controlling the rate of heating and cooling.
3. Compensate for difference in the thermal conductivity, melting point and electrical resistance. This may be achieved by using different tip areas and shapes of electrodes on both sides of spot- or seam-welded sheets; or in the case of resistance butt welding by clamping the two dissimilar metals at unequal distances from the joint.

Corrosion resistance is another factor which must be taken into consideration when welded joints of dissimilar metals are placed in service under conditions in which they will be exposed to corrosion.

There are many industrial applications in which it would be desirable to join Monel and mild steel into a fabricated article or structure which would possess the high corrosion resistance, strength and hardness of the Monel and the economy and general service characteristics of the mild steel. These two metals have been successfully joined by the various fusion-welding methods, but very little information is available on the resistance-welding methods of joining these metals. This investigation was undertaken for the purpose of obtaining the conditions necessary for the satisfactory seam welding of these two dissimilar metals. The 0.062-in. sheet thickness was chosen as typical of many applications, but the same general conditions should hold true in seam welding other gages.

## MATERIAL

The 0.062-in. Monel used in this investigation was cold rolled and annealed. The 0.062-in. steel was a low-carbon, S.A.E. 1015 steel, hot rolled. The average mechanical properties and physical constants of these materials are given in Table 1.

### *Material Surface Treatment*

*Monel*—The 0.062-in. Monel strip, as-received, possessed an excellent surface finish with no visible surface oxide. All Monel was degreased prior to welding by one of the following methods: (1) immersion in boiling trisodium phosphate solution; (2) placing in a polychlorethylene vapor-degreaser; (3) swabbing with carbon tetrachloride.

Surface contact resistance measurements were made with a Kelvin-Double-Bridge circuit described in a previous report from this laboratory.[2] The measurements on Monel sheet after degreasing showed values ranging from 900 to over 1100 microhms. As variations in weld strengths often result from high values of surface-contact resistance, it was thought advisable to pickle the Monel to reduce this resistance to a low value. A 50% nitric acid solution was used for flash pickling, which lowered the surface-contact resistance to a range of 35–60 microhms. Surface contact resistances of this magnitude were found extremely favorable, from the welding standpoint.

*Steel*—The S.A.E. 1015 steel, as-received, had been commercially pickled and covered with a coating of machine oil to prevent rusting during storage. After degreasing in a carbon tetrachloride bath, the material was flash pickled in a 50% hydrochloric acid solution. The magnitude of the surface contact resistance after this pickling lay in the range of 30–60 microhms and proved to be entirely satisfactory.

**Ernest F. Nippes, Allan R. Pfluger** and **Gerald M. Slaughter** are associated with the Welding Laboratory, Dept. of Metallurgy, Rensselaer Polytechnic Institute, Troy, N. Y.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

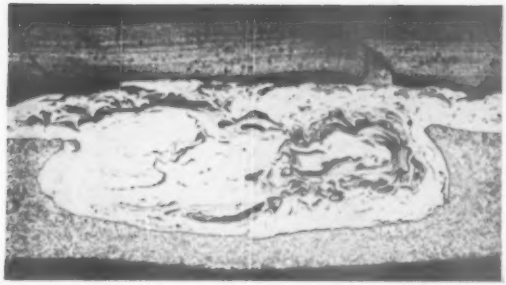

*Fig. 1 Seam Weld showing fusion in both metals with resultant stirring action. 18 × (Monel on top in this and subsequent Figs.)*

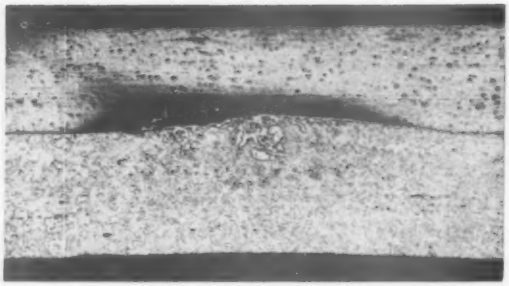

*Fig. 2 Seam Weld showing penetration of Monel into steel. 18 ×*

## EQUIPMENT

A 175-kva. Federal seam welder of the press type was employed in this investigation.

The welding wheels were of an R.W.-M.A. Class 2 electrode material and had a nominal diameter of 10 in. They were driven by a variable speed Reeves drive.

The welding current was regulated by means of phase control of the ignitron tubes in series with the primary of the welder transformer. The timing control system was of the synchronous electronic type. Welding current was measured oscillographically.

A 150-kva. X-ray unit was used to radiograph the welds and a highly sensitive, fine-grained film served as the recording medium.

The hydraulic system used to test the pillow specimens consisted of a hand-operated pump with a maximum capacity of 3000 psi. to supply the necessary pressure, and a hydraulic gage to measure the pressure. The fluid used was water to which about 5% of a soluble oil had been added.

## PROCEDURE

At the outset, an attempt was made to make welds by melting both metals. An example of a typical weld made by this method is shown in Fig. 1, in which severe mixing and alloying of the two metals is evident. Monel, having a lower melting point than the steel, is the first to fuse and form a molten nugget. As the melting point of the steel is approached, the Monel tends to penetrate between the low melting grain boundaries of the steel as shown in Fig. 2. Upon reaching the melting point of the steel the electromagnetic forces of the welding current act on the molten liquid conductor and create a violent stirring action. This may be seen in Fig. 1. This stirring action has been described by Unger,[4] who found in welding Cor-Ten (a low-alloy high-tensile steel) to 18-8 stainless steel that welds made by melting and mixing of the two metals were unsatisfactory. As a result, Unger developed a spot-welding procedure for making welds without mixing, by only fusing the stainless steel.

Radiography of welds made by melting both the Monel and steel with the severe mixing as seen above showed considerable porosity and cracking. In some extreme cases, visual inspection showed large cracks penetrating to the surface of the Monel in the welded seam. This excessive porosity and cracking should be avoided if a pressure-tight, high-strength seam weld of good appearance is to be produced. In view of the above difficulties associated with mixing, it was decided to investigate the possibilities of making sound welds with fusion occurring only in the Monel.

In resistance welding, the amount of heat generated depends primarily upon the current flowing through the pieces to be welded and the resistance, which consists of three parts, the contact resistance between the two sheets to be welded, the resistance of the sheets themselves and the resistance between the electrodes and the work. In the welding of similar metals the contact resistance between the two sheets is usually the greatest and therefore the greatest heating occurs at the sheet-to-sheet interface. In the welding of dissimilar metals, however, the maximum resistance may not exist at the sheet-to-sheet interface, but may actually be located within one of the metals due to a high specific resistance. Another factor which must be taken into consideration is the thermal conductivity of the two metals. The metal with the higher thermal conductivity will tend to be cooler due to the heat being conducted away more rapidly. As there is a definite relationship between the electrical and thermal conductivity of alloys, wherein a metal with a high specific resistance will have a low thermal conductivity, it is entirely possible that the greatest amount of heat may be concentrated within one of the two metals.

A comparison of the electrical and thermal properties of Monel and low-carbon steel is shown in Table 1. It may be seen that the Monel has both a much higher electrical resistivity and a lower thermal conductivity than the steel. Therefore, the greatest amount of heat should be generated within the Monel. As the Monel also has the lower melting point it should be entirely possible to have melting occur only in the Monel.

**Table 1—Average Mechanical Properties and Physical Constants of Monel and Low-Carbon Steel**

| | *Monel* | *0.2% carbon steel* |
|---|---|---|
| Yield strength (0.2% off set), psi. | 35,000 | 45,000 |
| Tensile strength, psi. | 75,000 | 69,000 |
| Elongation in 2 in., % | 40 | 30 |
| Melting point, ° F. | 2370–2460 | 2,760 |
| Specific heat (32–212° F.), Btu./-lb./° F. | 0.13 | 0.107 |
| Thermal expansion coefficient (32–212° F.), $10^{-6}$ in./in./° F. | 7.8 | 6.7 |
| Thermal conductivity (32–212° F.), Btu./sq. ft./-hr./° F./in. | 180 | 460 |
| Electrical resistivity (32° F.), ohms./cir. mil ft. | 280 | 60 |

With the feasibility of fusing only the Monel established, it was then necessary to determine the welding conditions for obtaining sound high-strength welds. The remainder of the investigation was primarily concerned with the determination of the optimum values of the seam welding variables; weld On time, electrode force, weld Off time, weld spacing and welding current.

### *Determination of Weld On Time and Electrode Force*

Before attempting to establish the optimum welding conditions by seam welding, it was thought desirable to employ spot welding and thereby avoid several extra variables inherent in the seam-welding process. Accordingly, for the

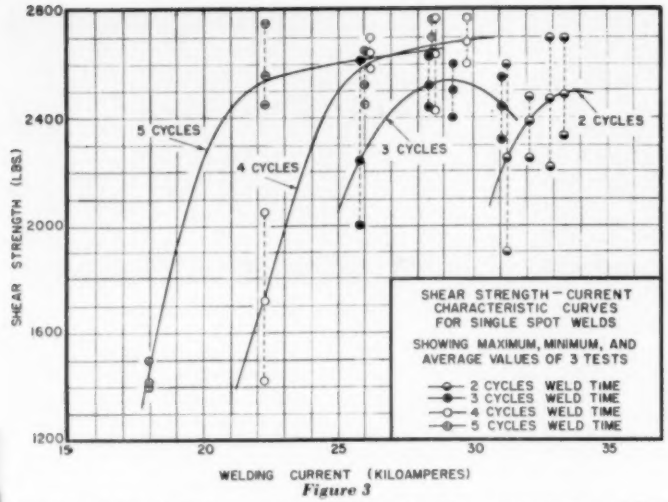


*Figure 3*

determination of weld On time a series of single-spot lap welds of Monel to steel were made and tested in tensile-shear. One-inch wide Monel and steel strips were spot welded using the seam-welding electrodes. All specimens were radiographed to determine presence of porosity, cracking and expulsion. Mixing of Monel into the steel was determined by metallographic sectioning.

From previous experience it was known that reasonably satisfactory welds could be made with an electrode force of 2000 lb. Using this value of electrode force, three specimens were made at each of a number of welding currents for values of weld time of 2, 3, 4 and 5 cycles.

It was found that welds made at currents below the point where "spitting" or slight expulsion of metal occurs tended to fail in brittle shear. Welds made at currents above the expulsion point tended to fail in a ductile tear in the heat-affected zone of the steel. These results showed strikingly that high-strength welds of Monel to steel could be made only with the high values of welding current obtained above the expulsion point. Consequently, these higher values of welding current were used in the following portions of the investigation.

The results of the tensile-shear tests were plotted as shear strength vs. welding current. As is shown in Fig. 3, the maximum strengths for all the weld times investigated were approximately the same.

For the 2-cycle welds, only a relatively small current range was investigated, since the current necessary to adequately fuse the Monel was greater than the capacity of the seam-welding machine. A spot weld made with 2 cycles weld time is shown in Fig. 4, in which it is apparent that sufficient current was not available to adequately fuse the Monel. With the 3-cycle welds it was possible to investigate a wider current range. A 3-cycle weld is shown in Fig. 5 where fusion of the Monel is more complete with greater resultant penetration. Slight porosity was detected in both the 2- and 3-cycle welds at high-current values, whereas at low-current values welds tended to fail in brittle shear.

The welds made with 4 and 5 cycles weld time were characterized by mixing, bad porosity and cracking as may be seen in Figs. 6 and 7. In Fig. 6, at 4 cycles, mixing is readily apparent and some porosity may also be seen. In Fig. 7, at 5 cycles, mixing and alloying are more

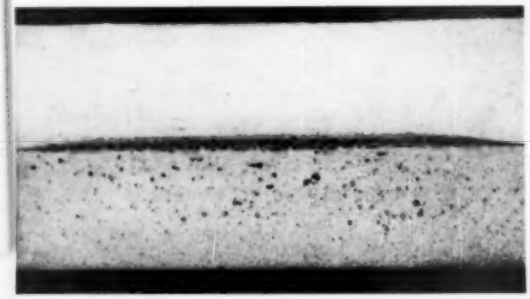

*Fig. 4 Two-cycle spot weld showing slight fusion in Monel. 18×*

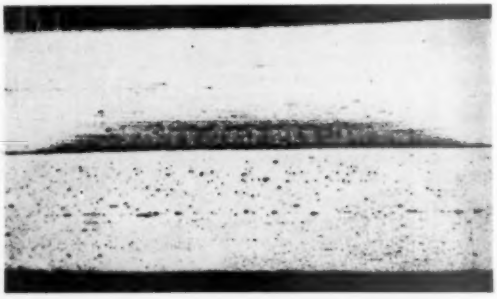

*Fig. 5 Three-cycle spot weld showing greater fusion in Monel. 18 ×*

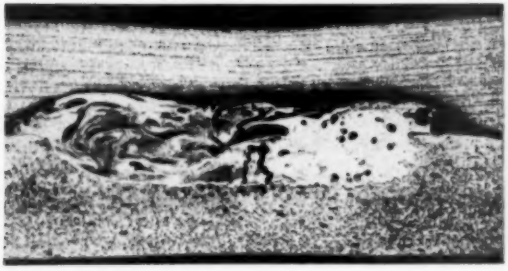

*Fig. 6 Four-cycle spot weld showing mixing and some porosity. 18×*

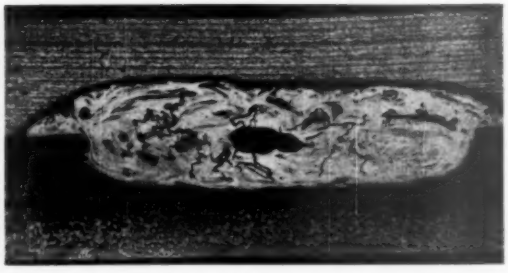

*Fig. 7 Five-cycle spot weld showing more complete mixing. 18 ×. A large void and cracks may also be seen*

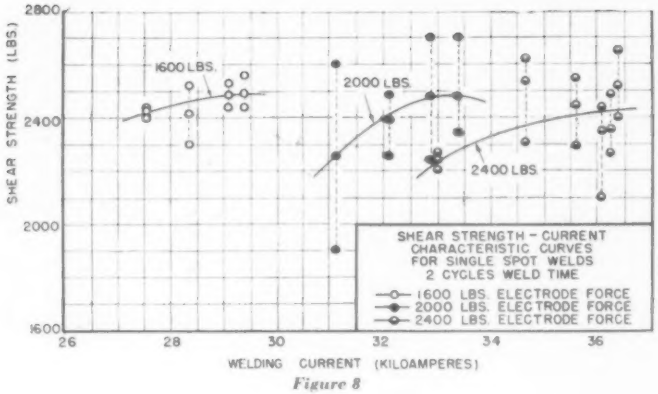


*Figure 8*

complete. A large void is visible in the center and cracks may be seen throughout the weld nugget. Thus, the possibility of using the longer weld times of 4 and 5 cycles was eliminated. But the question of whether to use 2 or 3 cycles weld time could only be answered by further investigation.

Series of spot welds at 2 and 3 cycles weld time were made with electrode forces of 1600, 2000 and 2400 lb. and their strength-current curves are shown in Figs. 8 and 9. With the 2-cycle weld time, a wide current range may be seen to exist at 1600-lb. electrode force in which high-strength welds were made, but with severe porosity. At the higher values of electrode force, the current range was too narrow, and there was a definite tendency for the welds to fail in brittle shear.

With the 3-cycle welds, severe porosity was again present in the welds made with 1600-lb. electrode force. With 2000-lb. electrode force, porosity occurred in the high-strength welds and the current range was limited. The best shear-strength-current curve was found to result from the use of a 3-cycle weld time and 2400-lb. electrode force. A wide welding current range existed at which high-strength welds could be made, and the maximum shear-strength appeared to be noticeably higher than that obtained with 3-cycle welds at the lower electrode forces. Porosity occurred within this current range but did not become severe except in the upper limits where mixing began. Metallographic sectioning indicated that the penetration in the Monel was in the order of 15–20%. As a result of the above single-spot weld investigation, the optimum weld On time of 3 cycles and the optimum electrode force of 2400 lb. were established.

### *Determination of Weld Off Time*

With the weld On time and electrode force determined, the next step was the determination of weld Off time. Since previous experience had indicated that a weld Off time of greater duration than the On time was highly desirable in seam welding Monel, series of seam welds were made at timing cycles of 3 on—6 off, 3 on—9 off and 3 on—12 off. All welds were radiographed and welds in each series were sectioned for metallographic examination.

Radiographic inspection of these welds indicated that porosity tended to decrease as the Off time increased. As cracking was evident in high-current welds made with the 3 on—6 off timing cycle, it was evident that an Off time of greater than 6 cycles was necessary to avoid this defect. As a result of the above investigation the 3 on—12 off timing cycle was chosen as the most satisfactory from the standpoint of cracking and porosity. Greater weld Off times, while possibly giving slightly less porosity, were not deemed practical because of extremely low welding speeds. At a slight sacrifice in porosity, Off times as low as 9 cycles were found satisfactory, but any further decrease was not advisable.

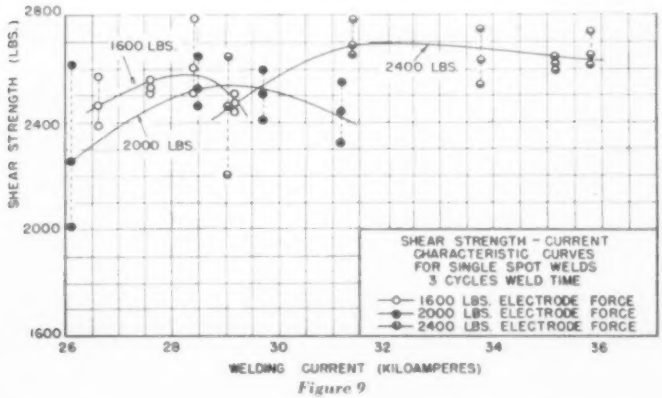


*Figure 9*

### *Determination of Weld Spacing and Welding Current*

As seam welding is characterized by a series of overlapping spot welds, one of the most important variables is weld spacing. If a pressure-tight seam is desired, it is obvious that the number of spots per inch of weld seam must be sufficient to prevent leakage between weld nuggets. It was found that welds do not necessarily have to overlap to obtain pressure-tightness, but some overlap is desirable.

In order to determine the optimum conditions for seam welding, it is first necessary to establish a suitable test to determine the strength and pressure tightness of the welded seam. The conventional tensile-shear test used for evaluating the strength of spot welds is not applicable in the case of seam welding where an indication of the pressure tightness of the seam is desirable. It is entirely possible for a seam weld to show high strength in this test but yet lack pressure tightness because of insufficient weld overlap. The normal tension test is not applicable because it is difficult to establish equal cross-sectional weld areas from specimen to specimen.

The pillow test was decided upon because it is the only test which approaches operating conditions of a seam-welded joint, and which will determine both the strength and the pressure-tightness of the welded seam. The pillow test specimen, shown in Fig. 10, was constructed from one flat 6- x 6-in. sheet of Monel and one 6- x 6-in. sheet of steel. Previous to seam welding, a small hole was drilled in the center of the steel sheet and a $^{3}/_{8}$-in. pipe nipple was centered over the hole and arc welded to the sheet. The steel and Monel sheets were placed together and tacked by spot welding in the corners to facilitate handling. Seam welds were then made parallel to the four specimen edges so as to enclose a 4- x 4-in. area.

Several series of pillow-test specimens were made at weld spacings of $5^{1}/_{2}$, $6^{3}/_{4}$ and $7^{1}/_{4}$ welds per inch at various values of welding current. The pillow specimens were attached to the previously described hydraulic system and the hydrostatic pressure gradually increased until rupture occurred. The pressures (in psi.) at which

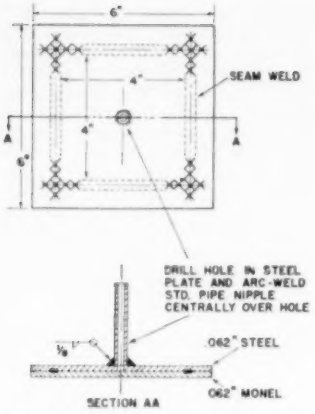


*Fig. 10 Details of pillow-test specimen*

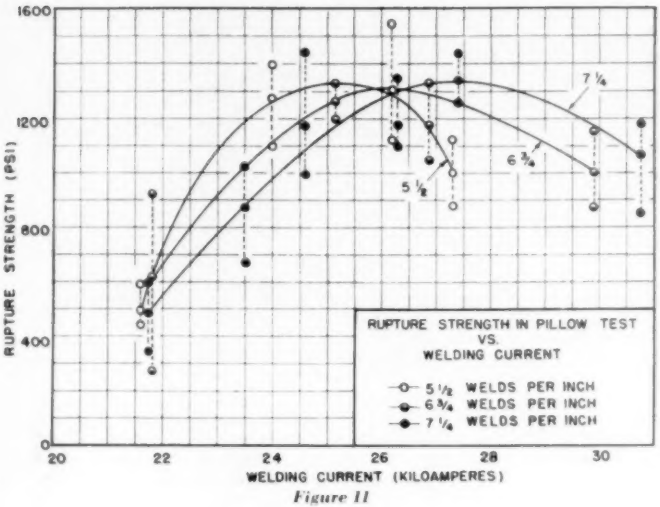


*Figure 11*

the pillows ruptured were recorded along with the seam in which the fracture occurred and the location of the fracture in the seam. Curves of rupture strength vs. welding current were plotted and are shown in Fig. 11.

Approximately the same maximum strengths were reached with all weld spacings tested. With a greater number of welds per inch it was found that the same rupture strength occurred at higher current values. This is due to an increased short-circuiting of the welding current. Weld spacings of more than $7^1/_4$ welds per inch were not included in this portion of the investigation because pressure tightness could be achieved with as low as $5^1/_2$ welds per inch. Furthermore, too great a weld overlap increased the tendency toward mixing.

Since the object of this portion of the investigation was to determine the weld spacing which would give the widest range of welding current in which high-strength sound welds could be made, the three curves were compared on this basis. The lower limit of the current range is set by shear failure through the weld zone at low-rupture pressures. The upper limit is governed by two factors, the beginning of mixing and severe porosity, and the decrease in strength at the high-current end of the strength-current curve.

The current range was narrow in the case of welds made with a spacing of $5^1/_2$ spots per inch, and metallographic sectioning showed that the welds did not quite touch. Both the $6^3/_4$ and $7^1/_4$ weld spacings had a considerably wider current range, and the welds overlapped about 10–20%. Photomacrographs of welds made at spacings of $5^1/_2$ and $7^1/_4$ welds per inch are shown in Figs. 12 and 13, from which the better penetration and overlap of the $7^1/_4$ welds per inch spacing is readily apparent. From the above results an optimum weld spacing of 7 welds per inch was chosen.

The welding current range necessary to produce these high-strength pressure-tight welds was found to lie between 24,000 and 27,000 amp. Below this range, welds failed in shear and, above it, contained mixing and porosity with a resultant decrease in strength. These values of welding current are only given as a guide, since the magnitude of current necessary for resistance welding is largely dependent upon the individual welding machine. Therefore, the current range for a given application should be determined and the optimum welding current chosen within this range.

## DISCUSSION

In previous work on the seam welding of Monel to low-carbon steel it had been reported that severe cracking occurred in the joint. This is undoubtedly due to mixing and alloying of the two metals as a result of a long weld On time. Seam welding differs from spot welding in that the electrode force does not remain constant during the formation of the weld nugget. When using long On times part of the weld nugget is formed and then the electrodes roll away decreasing the forging pressure.

*Fig. 12 Longitudinal section of seam weld—$5^1/_2$ welds per inch, showing no overlap. 18 ×*

*Fig. 13 Longitudinal section of seam weld—$7^1/_2$ weld per inch, showing good overlap. 18 ×*

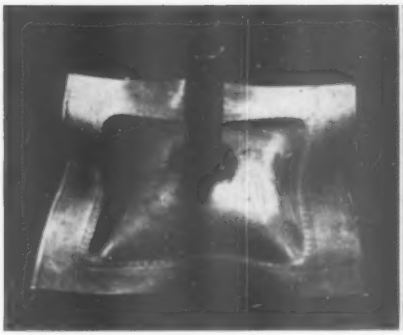

*Fig. 14 Photograph of pillow, tested as-welded*

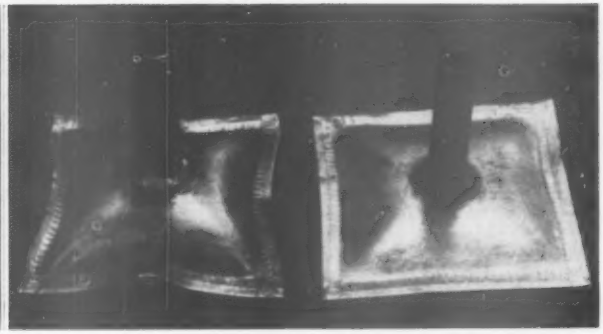

*Fig. 15 Photograph of pillows, sheared before testing. Two pillows are shown, one which failed at high pressure and another which failed at lower pressure*

When welding a dissimilar metal combination such as Monel and steel, where there may be alloying and the formation of brittle intermetallic compounds, it is essential that the proper forging pressure be maintained during the formation of the nugget to avoid cracking. There are two ways of achieving this aim. The best method is the use of an intermittent drive in which the wheels travel a fraction of an inch, stop, make a spot and advance a fraction of an inch into position to make the next overlapping spot. However, this method involves the use of complicated gearing arrangements in the wheel drive mechanism and is rather slow. The other method is to reduce the ratio of weld On time to Off time and weld at a somewhat slower wheel speed. The use of low-inertia type welding heads should also be of advantage in maintaining adequate forging pressure.

In this investigation the above difficulties were avoided by having fusion occur only in the Monel. This results in the formation of a braze type bond where the interatomic forces acting at the interface contribute to the strength. An idea of the strength of such a bond may be obtained from a comparison of the rupture pressures in a series of pillow tests of welds of Monel to Monel, steel to steel and Monel to steel, which failed at approximate values of 1500, 1250, and 1300 psi., respectively. Thus, it can be seen that this type of bond is at least as strong as a regular seam weld in steel.

At the outset of the investigation, $^3/_8$-in. wheels 10 in. in diameter beveled to a face width of $^3/_{16}$ in., were used. Later it was found that a great reduction in porosity and much better surface appearance of the welds were achieved by using a 6-in. radius dome-type face.

It was noted that as welding progressed over the first few inches of a seam, the plate temperature close to the electrodes gradually built up and reached a steady state value during the remainder of the seam. This phenomenon resulted from the flow of heat outward from the previously formed welds in the seam. To avoid any variations in heating when welding the short pillow seams, several pulses of welding current were passed before motion of the wheels began. This gave a preheating effect, which established more rapidly the heat-flow conditions occurring in a longer seam.

At first the specimens were tested as-welded, in which case the skirt of metal outside the welded seam tended to buckle unevenly. As it was found that this buckling often led to inconsistencies in the pillow test results, the remainder of the pillows were sheared close to the outer edge of the seam before testing. A photograph of a pillow tested as-welded is shown in Fig. 14. Two pillows which were sheared before testing are shown in Fig. 15.

An interesting observation was made during the course of an examination of radiographs of welds showing mixing in a longitudinal metallographic section. Light mottled areas were seen on the radiographs in the weld zone at the same location that mixing was observed in the section. An example of this mixing is shown in Fig. 16 (*a*), a print of a radiograph. It should be borne in mind, however, that light areas on a radiograph appear as dark areas on a print. For comparison purposes, a print of a radiograph exhibiting no mixing or porosity is shown in Fig. 16 (*b*).

On a radiograph, light areas may be caused by two conditions. The first condition is a variation in thickness of the metal being X-rayed. However, in the present situation, the only variations in thickness occurred as a result of the ridges inherent in the seam-welding process, whereas the light areas under consideration did not occur at the same positions in the weld seam. The second condition, which could only occur when two or more metals are present, comes about as a result of the metal having the highest X-ray absorption coefficient penetrating into the body of the other metal. This effectively increases the amount of high-density material in a given thickness.

In the present investigation fused Monel, an alloy of copper and nickel, is stirred into the steel. At the 100-kv. tube voltage used, the X-ray absorption coefficients of copper, nickel and iron are 1.55, 1.45, and 1.10, respectively. Thus, if a fairly high percentage of Monel was present in the steel, the over-all absorption coefficient would be higher in this area. Thus, in the area where the Monel was mixed into the steel a greater absorption of X-rays would occur and light areas would show on the radiograph. The above reasoning appears to substantiate the use of radiography as a means for the detection of the presence and extent of mixing in a weld of two metals having

*Fig. 16 (a) Print from a radiograph showing mixing*

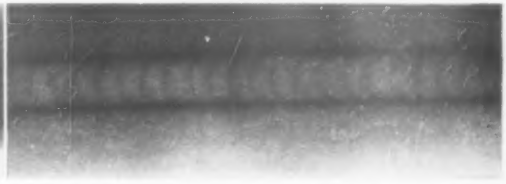

*Fig. 16 (b) Print from a radiograph showing a sound weld*

widely different X-ray absorption coefficients.

## CONCLUSIONS

As a result of this investigation it may be concluded that:

(1) For the weld times investigated, fusion of both the Monel and steel in the resistance-welding process results in a heterogeneous mass of weld metal and may lead to porosity and cracking in the weld zone.

(2) To avoid the above porosity and cracking, seam welds of Monel to steel may be made with fusion occurring only in the Monel. For the 0.062 gage, the optimum seam-welding conditions are:

(*a*) Weld On time—3 cycles
(*b*) Weld Off time—12 cycles
(*c*) Electrode force—2400 lb.
(*d*) Weld spacing—7 welds per inch
(*e*) Weld speed—34 in. per minute
(*f*) Welding current—24,000 to 27,000 amp.

(3) To insure the best welding consistency, it is important to carefully clean and pickle both the Monel and steel prior to welding.

(4) The pillow test is a valuable aid in determining the strength and pressure-tightness of seam welds.

(5) A minimum of porosity and much better surface appearance result from the use of an electrode having a 6-in. radius dome-type face.


## ACKNOWLEDGMENT

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# Stress Corrosion Cracking of Mild Steel

***A progress report in the investigations of stress corrosion cracking of mild steel wires covering effects of heat treatments and concentration and composition of corroding liquid***


*by Daniel Cubicciotti and William Boyer*



## SUMMARY

A STUDY of the stress corrosion cracking of mild steel wires has been made in which the influence of temperature and gaseous atmosphere during heat treatment of wires was studied as a function of the time required to break the wires, and the effect of variation in the concentration and composition of the corroding liquid on the time required to break the wires was investigated.


## INTRODUCTION

In the field of corrosion, one of the most striking phenomena is the stress corrosion cracking of metals. The mechanism by which deep cracks are formed in a piece of metal that is otherwise little attacked by the corroding liquid is very interesting. The present study was undertaken to discover some of the characteristics of this type of corrosion in mild steel.


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The stress corrosion of mild steels has been reported in the literature under various names for many years; however, not many controlled quantitative experiments have been described. In fact, one author has remarked that a large part of the literature in the field consists of reviews rather than new experimental data.[6] It has been established, however, that the stress corrosion cracking of mild steels occurs intergranularly[1] (also reference 8, p. 3) and several solutions can cause the phenomena.[9] In addition, heat treatment of the steel in certain gas atmospheres appeared to alter its stress-corrosion characteristics.[3] (Also reference 8, p. 59.)

It was the purpose of the present work to gather quantitative data on the effect on the stress corrosion of mild steels of such variables as the heat treatment of the metal or the concentration and composition of the corroding liquid. Although the work is not a comprehensive study, it is the opinion of the authors that some interesting facts have been brought to light.

## EXPERIMENTAL METHOD

In order to subject a sample of steel under known

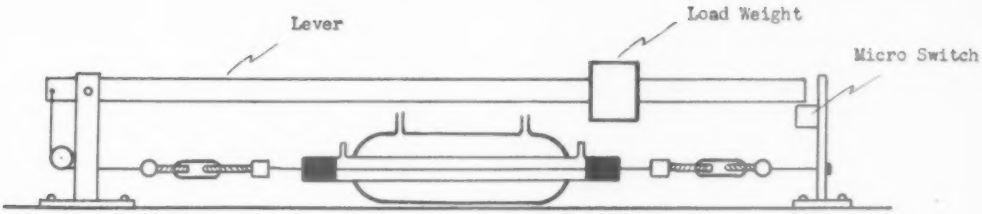


*Fig. 1 Apparatus for stress corrosion testing*

stress to the action of a corroding fluid, the apparatus shown in Fig. 1 was used. A steel wire was clamped at either end and stressed with a lever and weight system. The clamps were short pieces of rod with small holes through the center for the wire and setscrews to grip the wire. One end of the wire was connected to the lever by means of a flexible steel cable and pulley. Surrounding the wire was a double-walled glass jacket the inner tube of which kept the corroding fluid in contact with the wire, while the outer tube of the glass jacket was used to maintain the liquid and wire at constant temperature. For the 100° C. runs steam was passed through this outer tube, and for the 87 and 111° C. runs trichloroethylene and toluene, respectively, were refluxed inside the outer jacket. The two ends of the inner glass tube were closed by one-holed rubber stoppers, the wire passing through the hole, and the holes in the stoppers were packed with paraffined string wound around the wire.

In a typical run, the wire sample was threaded through the rubber stoppers in the glass jacket and clamped at either end to the turnbuckles. Then, with the weight at the proper position on the lever arm, the turnbuckles were tightened until the lever was horizontal and clear of the end rests. Paraffined string was wrapped around the ends of the wire and forced into the holes in the rubber stoppers. The jacket and wire were brought to the desired temperature by heating the outer part of the jacket with steam or boiling liquid, and the inner tube of the jacket was filled completely with the corroding liquid at the proper temperature, and a timer started. When the wire finally broke, the long arm of the lever fell on a microswitch and stopped the timer, thus recording the time required to break the specimen. At the end of the run the wire was examined for stress corrosion cracks and general corrosion.

The steel samples used in the experiment were all from the same batch of mild-steel wire, 0.041 in. in diameter, with analysis as follows:

| | % |
|---|---|
| C | 0.060 |
| Mn | 0.360 |
| P | 0.010 |
| S | 0.026 |
| Si | 0.005 |
| Al | 0.022 |
| N (total) | 0.003 |

Grain size measurements on several wires after heat treatment were made by polishing a transverse section of the wire, etching with 10% nital, observing under 100 diameters magnification and comparing them with standard pictures.[1] In addition, on some wires a yield point was measured, which was taken to be the stress at which the wire stretched plastically.

During the course of the work it was found necessary to heat treat the wire samples as follows. Several wires were packed tightly into a Vycor glass tube, and the tube placed in an electric furnace already at temperature. The furnace was maintained at the required temperature ±10° for the desired length of time and then allowed to cool, the wires cooling with the furnace. If some gaseous atmosphere other than air was required in the heat treatment, the Vycor tube containing the samples was quickly evacuated after being placed in the furnace, and the proper gas introduced at one atmosphere pressure. The heat-treated wires were subjected to stress-corrosion testing without subsequent treatment. The gases used were of commercial purity and chemicals used were all chemically pure.

## EXPERIMENTAL RESULTS

At the outset of this work many unsuccessful attempts were made to observe stress corrosion on unannealed wires, using concentrated calcium nitrate-ammonium nitrate solutions at 100°. After several hundred minutes' exposure under stresses close to the tensile strength, only general corrosion was observed and rupture of the wire was accompanied by "necking" at the break.

Smialowski[7] reported stress corrosion failure in short periods of time of iron wires under attack by hot ammonium nitrate solutions. However, he mentioned heating the wires momentarily with a burner. When several wires were heat treated in a furnace and tested by the present authors, the wires broke under stress corrosion in short periods of time. Therefore the heat treatment was apparently required in order for the wires to stress corrode.

The results of tests made under different conditions are given below. In each run reported as stress corrosion failure, the sample showed one or more of the characteristics of that type of corrosion, namely: sharp breaks with little or no "necking," transverse cracks in the wire other than at the rupture and absence of pitting or general corrosion.

### *Influence of Heat Treatment*

The effect of the temperature of heat treatment of the wires was thoroughly investigated, using an atmosphere of air, and a few heat treatments were made at different temperatures using other gaseous atmospheres. Tests of these heat-treated specimens were made under conditions of constant stress and constant solution, and the results of these experiments are given in Table 1.

In Table 1 each group of runs averaged corresponds to one batch of heat-treated wires; therefore, the differences in breaking time among runs in a group are caused by errors in the method and not by differences in heat treatment. These differences in breaking times are usually not very large.

It may be seen from Table 1 that some heat treatment of the wire is required to give rise to stress corrosion; that is, an untreated wire (runs 87 and 93) broke not from stress corrosion but from reduction of the diameter of the wire by general corrosion. Furthermore, it is apparent that heat treatment must be more severe than 1 hr. at 600° C. since samples so treated under nitrogen (runs 94 and 95) did not break from stress corrosion.

For the specimens heat treated in air, the breaking time decreased with increase in annealing temperature from 760 to 885° C., but above 885° the breaking time increased with temperature. In the nitrogen-treated wires, the breaking time decreased as the annealing temperature was increased from 760 to 850° C.; however the breaking times of two batches of wires treated at 750 and 760° do not agree. In vacuum, the time of breaking decreased as the annealing temperature was increased from 760 to 860°. The hydrogen and helium treatments, however, showed no real differences in breaking times between the 750 and 850° anneals. Yield points were determined on several differently heat-treated wires to see whether there were any radical differences in the strengths of the various specimens after heat treatment. Inasmuch as the tensile strength of these wires was difficult to determine, the point at which the wire deformed plastically was observed. The results of this test, given in Table 2, show that there was little variation in the strengths of the wires after the different heat treatments.

**Table 1—Time Required to Break Samples After Various Heat Treatments**

Conditions: 50 wt % $NH_4NO_3$ at 100°C., 40,100 psi. stress.

| Run | *Annealing temperature, ° C.* | *Breaking time, min.* | *Average of breaking times, min.* |
|---|---|---|---|
| | Air atmosphere during heat treatment | | |
| 87 | Untreated | 856* | .. |
| 93 | Untreated | 275* | .. |
| 33 | 760 | 63.2 | 63 |
| 34 | 760 | 62.6 | |
| 35 | 820 | 44.3 | 52 |
| 36 | 820 | 59.9 | |
| 31 | 830 | 45.7 | 52 |
| 32 | 830 | 58.2 | |
| 23 | 885 | 41.5 | 39 |
| 24 | 885 | 31.7 | |
| 25 | 885 | 43.8 | |
| 6 | 920 | 59.5 | 62 |
| 7 | 920 | 58.7 | |
| 8 | 920 | 57.6 | |
| 9 | 920 | 57.1 | |
| 10 | 920 | 66.5 | |
| 11 | 920 | 76.2 | |
| 13 | 980 | 61.9 | 76 |
| 16 | 980 | 90 | |
| | Nitrogen atmosphere | | |
| 94 | 600 | 92.5* | .. |
| 95 | 600 | 81.4* | .. |
| 69 | 750 | 64.6 | 62 |
| 80 | 750 | 58.5 | |
| 53 | 760 | 84.1 | 79 |
| 54 | 760 | 73.2 | |
| 55 | 860 | 53.5 | 51 |
| 56 | 860 | 47.9 | |
| | Vacuum ($10^{-2}$ mm. pressure of air) | | |
| 37 | 760 | 71.9 | 77 |
| 38 | 760 | 81.1 | |
| 39 | 870 | 58.3 | 59 |
| 40 | 870 | 59.2 | |
| | Hydrogen atmosphere | | |
| 44 | 750 | 49.3 | 49 |
| 45 | 750 | 49.7 | |
| 49 | 850 | 46.5 | 48 |
| 50 | 850 | 49.9 | |
| | Helium atmosphere | | |
| 67 | 750 | 52.0 | 56 |
| 68 | 750 | 60.6 | |
| 101 | 885 | 55.8 | 56 |

* Not stress corrosion breaks but general corrosion.

**Table 2—Yield Points of Wire Specimens After Heat Treatment**

| *Heat treatment* | | | *Yield point,* |
|---|---|---|---|
| *Temp., ° C.* | *Atmosphere* | *Time, hr.* | *psi.* |
| 760 | Air | 1 | 38,000 |
| 760 | Vacuum | 1 | 38,000 |
| 750 | Hydrogen | 1 | 36,000 |
| 760 | Nitrogen | 1 | 36,000 |
| 740 | Nitrogen | 1½ | 38,000 |
| 740 | Nitrogen | 2 | 38,000 |
| 830 | Air | 1 | 39,000 |
| 820 | Air | 1 | 36,000 |
| 870 | Vacuum | 1 | 39,000 |
| 850 | Hydrogen | 1 | 36,000 |
| 860 | Nitrogen | 1 | 39,000 |

Experiments were made to determine the effect of the duration of the heat treatment, and the results are shown in Table 3. It appears from these experiments that increasing the time of heat treatment from 1 hr. to 1½ hr. decreased the breaking time, but the increase from 1½ to 2 hr. had no real effect.

**Table 3—The Variation of Breaking Time with Time of Heat Treatment**

Conditions: Nitrogen Atmosphere for Heat Treatment 50 Wt. % $NH_4NO_3$ at 100° C., 40,100 psi. Stress

| Run | *Annealing temperature, ° C.* | *Annealing time, hr.* | *Breaking time, min.* |
|---|---|---|---|
| 53 | 760 | 1 | 84 |
| 54 | 760 | 1 | 73 |
| 57 | 750 | 1½ | 45 |
| 58 | 740 | 2 | 50 |

Measurements made of the grain size in the body of several specimens of wire subjected to different heat treatments are given in Table 4. It can be seen that the differences in grain size are small and there is no apparent correlation with breaking time.

**Table 4—The Grain Size of Specimens After Various Heat Treatments**

| *Heat treatment* | *A.S.T.M. grain size number* | *Breaking time,* min.* |
|---|---|---|
| Untreated | 8 | — |
| 769°, air, 1 hr. | 8 | 63 |
| 760°, vacuum, 1 hr. | 6 | 77 |
| 750°, hydrogen 1 hr. | 8 | 49 |
| 860°, nitrogen, 1 hr. | 7 | 51 |
| 760°, nitrogen, 1 hr. | 7 | 79 |
| 740°, nitrogen, 2 hr. | 7 | 78 |

* From Table 1.

The several gaseous atmospheres used during heat treatment did not markedly affect the breaking time of the wires. From Table 1 it may be seen that all the wires treated at about 850° broke after approximately 50 min., while these treated in air, nitrogen or vacuum took somewhat longer. However, wires treated in nitrogen for more than 1 hr. at 650° also broke in about 50 min., as shown by Table 2. Thus it seems the gaseous atmosphere over the wire during the heating plays little if any part in altering the characteristics of the wire during stress corrosion.

### *Variation with Stress*

Since the variation of breaking time with applied stress has previously been measured by several authors[7, 10] only a short investigation of this effect was made in the present work. In Fig. 2 are shown the results of four tests at various stresses. It is interesting to note that for our experiments the rate of decrease of breaking time with increased stress is about 1 min. for each 1000 psi., while Smialowski[7] found about four times that value for similar wires.

### *Influence of Variations in the Corroding Liquid*

Previous workers have used 50% ammonium nitrate solutions as corroding liquids, presumably because of the greater effectiveness of the high salt concentration.

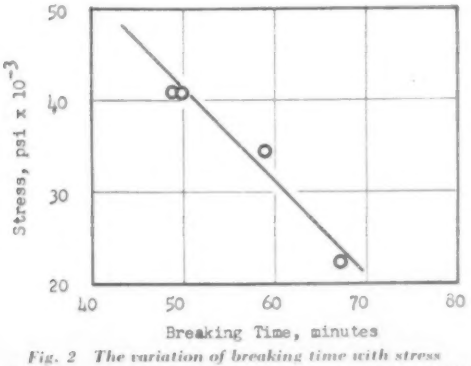


*Fig. 2 The variation of breaking time with stress*
Conditions: wire, hydrogen, 1 hr., 750° C. solution, 50 wt. % $NH_4NO_3$ at 100° C.

It seemed of interest, however, to observe the effect of lowering the concentration of the salt. For this work, several wires were heat treated together and tested with different concentrations of ammonium nitrate and the results are shown in Table 5 and Figure 3 (*a*).

In order to investigate the effect of varying the ammonium concentration independently of the nitrate concentration, solutions of ammonium nitrate and sodium nitrate were prepared in which the ratio of total number of moles of nitrate to moles of water was constant but the concentration of ammonium nitrate was not. The results obtained with these solutions are given in Table 6 and Fig. 3 (*b*). These data follow the same pattern as those of Table 5.

**Table 5—The Effect of Concentration of Ammonium Nitrate Solution on Breaking Time of Sample**

Conditions: Specimens Heated at 885° C. for 1 Hr. in Air, Stress 40,100 Psi.

| *Run* | *Ammonium nitrate concentration, wt. %* | *Breaking time, min.* |
|---|---|---|
| 23 | 50 | 42 |
| 24 | 50 | 32 |
| 25 | 50 | 44 |
| 28 | 40 | 58 |
| 27 | 30 | 46 |
| 29 | 20 | 143 |
| 30 | 10 | 326 |

The results of a parallel series of experiments to determine the effect of nitrate are given in Table 7. In this case, the ratio of moles of ammonium ion to moles of water was kept constant. With the nitrate were used two ammonium salts, ammonium sulphate and ammonium chloride. With the chloride as added salt,

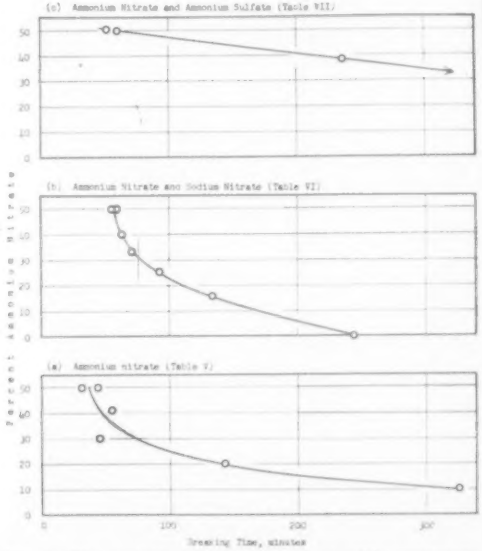


*Fig. 3 The variation of breaking time with concentration of solution*

**Table 6—Effect on Breaking Time of Concentration of Ammonium Ion in Constant Nitrate Concentration**

Conditions: Samples Annealed in Vacuum for 1 Hr. at 870° C., Stress 40,100 Psi.

| Run | *Ammonium nitrate concentration, wt. %* | *Sodium nitrate concentration, wt. %* | *Breaking time, min.* |
|---|---|---|---|
| 39 | 50 | 0 | 58 |
| 40 | 50 | 0 | 59 |
| 52 | 40 | 11 | 64 |
| 51 | 33 | 18 | 72 |
| 47 | 25 | 26 | 94 |
| 48 | 16 | 35 | 134 |
| 43 | 0 | 50 | 244 |

the wires after breaking were spotted with deep pits; the failure therefore may have been due to pitting rather than stress corrosion cracking. With the sulphate, some general corrosion was observed, and again it is not certain that the failure was caused by stress corrosion; however the very long breaking times of the wires in the sulphate-nitrate mixtures indicated that any stress corrosion was less intense than in the pure nitrate solution.

In Fig. 3 the effect of concentration of ammonium salts on the breaking time is shown graphically. Comparing graph 3 (*c*), in which only the nitrate concentration is varied, with 3 (*a*) and 3 (*b*), in which the ammonium concentration is varied, one sees that small changes in nitrate concentration have a larger effect than small changes in the ammonium concentration of the solutions.

**Table 7—Effect on Breaking Time of Nitrate Concentration in Constant Ammonium Concentration**

Conditions: Samples Annealed in Helium at 750° C. for 1 Hr., Stress 40,100 Psi.

| Run | *Ammonium nitrate concentration, wt. %* | *Ammonium chloride concentration, wt. %* | *Breaking time, min.* |
|---|---|---|---|
| 67 | 50 | 0 | 52 |
| 68 | 50 | 0 | 61 |
| 75 | 35 | 12 | 100* |
| 77 | 27 | 18 | 134* |
| 79 | 19 | 25 | 114* |
| 42 | 0 | 40 | >1131 |
| | | *Ammonium sulphate concentration, wt. %* | |
| 104 | 37 | 12 | 236† |
| 82 | 26 | 22 | 389† |
| 81 | 18 | 29 | 663† |

* Wire pitted.
† General corrosion.

In generalized acid theories ammonium ion may be considered an acid. Thus it seemed interesting to determine whether or not another acid nitrate would be effective in producing stress corrosion. Several nitrate salts with acidic cations, and sodium nitrate, which is a very weak acid, were tried in place of the ammonium nitrate. The results are tabulated in Table 8. All salts tried were more effective than ammonium nitrate except the manganous nitrate and the sodium nitrate,

**Table 8—Breaking Times of Wires in Various Nitrate Salts**

Conditions: Solution Temperature 100° C. Stress 40,100 Psi.

| Run | Salt | *Concentration of salt, wt. %* | *Breaking time, min.* |
|---|---|---|---|
| 43 | $NaNO_3$ | 50 | 244 |
| 73 | $Mn(NO_3)_2$ | 50 | >186 |
| 61 | $Al(NO_3)_3$ | 50 | 5 |
| 62 | $Zn(NO_3)_2$ | 50 | 3 |
| 65 | $Zn(NO_3)_2$ | 30 | 30 |
| 63 | $Zn(NO_3)_2$ | 10 | >1080 |
| 60 | $Mg(NO_3)_2$ | 48 | 19 |
| 72 | $Mg(NO_3)_2$ | 48 | 32 |
| 85 | $Mg(NO_3)_2$ | 48 | 24 |
| 86 | $Mg(NO_3)_2$ | 48 | 26 |
| 97 | $Mg(NO_3)_2$ | 48 | 22 |
| 111 | $Mg(NO_3)_2$ | 48 | 23 |
| 113 | $Mg(NO_3)_2$ | 48 | 22 |

which was so weakly acidic that it was not expected to be effective.

The attack by 50% zinc nitrate and by 50% aluminum nitrate was vigorous and similar to that of nitric acid itself; thus in those runs stress corrosion may not have been the cause of failure. However, the wire exposed to 30% zinc nitrate failed from stress corrosion, as evidenced by several cracks in the wire and the appearance of the break. It appears, then, that ammonium ion itself is not an essential constituent of the corroding liquid for stress corrosion but some acidic ion must be present.

To determine if some oxidizing agent other than nitrate might be effective in producing this type of corrosion, other oxidizing agents were used. One wire was exposed to a 50 weight per cent solution of ammonium dichromate at 100° C. After 330 min. in this solution at 40,100 psi. stress, the wire was removed intact and examined; it showed no evidence of any kind of corrosion. In a similar experiment, using 50 weight per cent ammonium sulphate with oxygen bubbling rapidly over the wire, the wire was removed, still unbroken, after 360 min. The wire was pitted and showed evidence of general corrosion but no cracks were visible.

In another series of experiments the temperature of the corroding liquid was varied. By boiling different liquids in the jacket it was possible to maintain the temperature of the liquid constant at different values. Three temperatures were used: 87, 100 and 111° C. In experiments using ammonium nitrate solutions, the change of breaking time with temperature was not much larger than the scattering between the breaking times at each temperature as shown in Table 9. The results with magnesium nitrate solution were more reproducible. It is interesting to note that the effect of temperature on breaking time is greater in the case of the magnesium solutions.

Finally, two experiments were made to establish the need for the simultaneous action of stress and corroding liquid. One sample of wire was subjected to a stress of 40,100 psi. for 120 min. and then 50% ammonium nitrate at 100° C. poured on it. The wire broke in 59 min. as compared to 65 min. for a similar wire on which

**Table 9—The Effect of Temperature of Corroding Liquid on Breaking Time**

| Run | Temperature of solution, ° C. | Breaking time, min. |
|---|---|---|
| 50 wt. % ammonium nitrate, stress 40,100 psi. Wire heated 1 hr. at 850° C. in hydrogen | | |
| 108 | 111 | 44.3 |
| 109 | 111 | 40.3 |
| 49 | 100 | 46.5 |
| 50 | 100 | 49.9 |
| 48 wt. % magnesium nitrate, stress 40,100 psi. Wire heated 1 hr. at 885° C. in helium | | |
| 100 | 111 | 12.8 |
| 112 | 111 | 14.8 |
| 111 | 100 | 22.8 |
| 113 | 100 | 22.4 |
| 114 | 87 | 66.7 |
| 115 | 87 | 65.1 |

stress and solution were applied simultaneously. Another sample of the same wire was exposed to 50% ammonium nitrate at 100° C. for 120 min. with no stress and then 40,100 psi. applied. This wire broke in 36 min. as compared to 65 for the normal procedure. It appears then that stress alone does not render the wire more susceptible to cracking, but exposure to solution alone does decrease the breaking time; however, the 120 min. exposure to solution decreased the cracking time only by about 30 min.

## DISCUSSION

The results show that some heat treatment of the wires used was necessary to give rise to stress corrosion. The wires as received had probably been cold worked in the drawing process. Since they did not crack if untreated, it is possible that the cold working of the metal acted as a preventative to stress corrosion.

The gaseous atmosphere used during the heat treatment had little effect on the breaking time of the wires. The heat treatment may have been effective only in allowing some constituent to diffuse into or out of the grain boundaries. Such a mechanism has already been proposed by other workers.[5, 8] The results given above, however, offer little confirmation of the "nitride precipitation" theory of Waber and McDonald;[8] in fact, they seem to contradict this theory. Iron nitride, which is the anodic material in the grain boundary according to that theory, is unstable at the temperatures used in the present heat treatments (see reference 8, p. 31); thus the heating should decompose the nitride and reduce the tendency of the wire to stress corrode. Further, a hydrogen atmosphere during the heat treatment should reduce the nitride concentration in the grain boundaries much more than a nitrogen atmosphere, and the breaking time of a hydrogen-treated wire would be greater than a nitrogen-treated wire; however just the opposite is observed for samples annealed at 750° and no difference for those heated at 850°.

Some insight into the mechanism of the attack on the metal by the liquid may be obtained from the concentration studies. It appeared from these experiments that in order to produce stress corrosion it was necessary to have nitrate present with an acidic cation. A possible interpretation of these results may be as follows. The nitrate oxidizes some intergranular material with the formation of cracks in the wire. The iron oxidized dissolves in the solution and is prevented from precipitation as oxides by the acidic cation. Thus the cracks formed are continually exposed to attack by the nitrate.

The rate of change of breaking time with temperature was found to be different for the two solutions used, indicating that the rate-determining step in the reaction causing the breaking is somewhat different in the two cases. Thus the rate-determining step is a reaction between some constituent of the solution and the metal, and not merely a reaction within the metal phase. If one plots the logarithm of the breaking time against reciprocal of the absolute temperature for the runs given in Table 9-2, the points fall on an approximately straight line. Assuming that the reciprocal of the breaking time characterizes some rate in the reaction, one may calculate an energy of activation for the reaction using the above-mentioned plot. This value is about 20 kcal. per mole.

The nature of the substance oxidized by the nitrate is not established by these experiments. It is apparently some substance formed or deposited in the grain boundaries by the heat treatment.

## ACKNOWLEDGMENT

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# Strain-Aging of Arc Welds in Mild Steel

**An investigation of the strain-aging characteristics of welds made with several types of modern covered electrodes. Certain aspects of the notch bend test are also discussed**

*by A. E. Flanigan, M. Kaufman and E. M. Emery*

## 1. INTRODUCTION

THE subject of this paper is but one aspect of a broader topic, the aging of steel. The latter subject has been reviewed recently by Epstein[1] and by Palm.[2]

Users of welded steel are often unaware that arc welds are capable of exhibiting aging phenomena. This is somewhat surprising in view of the fact that, earlier in the development of welding, bare electrode welds were known to be susceptible both to quench-aging* and to strain-aging.*

Several early investigators, including Doan,[3] Hensel and Larsen,[4] Kleinefenn,[5] and Hodge,[6] found the high-nitrogen weld metal produced with bare electrodes to exhibit quench-aging. It was reported by Doan that actual quenching was not required, the cooling rates encountered in welding sufficing to induce aging. Kleinefenn found bare-electrode welds to be susceptible to strain-aging as well as to quench-aging.

Without doubt, the aging tendency of bare-electrode welds was one of the factors reponsible for dissatisfaction with these electrodes and for the consequent development of modern electrode coatings.

Welds made with some of the early coated electrodes were studied by Doan,[3] by Kleinefenn,[5] and by Kuzmak.[7] Although the nitrogen content of the weld metal was substantially reduced, it was found that quench-aging could be produced. According to Kleinefenn, strain-aging occurred as well. An excellent and comprehensive review of this early work was written by Spraragen and Claussen in 1937.[8]

In spite of these early observations, interest in the aging of welds appears to have waned after the general acceptance of coated electrodes. This trend was inspired perhaps by the enthusiasm with which the new and generally superior electrodes were greeted.

Recently, spurred by failures in certain welded structures, there has been a renewal of critical interest in the mechanical properties of welded steel. In this connection, the writers have undertaken to re-examine the question of strain-aging.†

Interesting indications of strain-aging in arc welds have been reported recently by Bruckner and Ellis.[9]

## 2. THE SCOPE OF THE INVESTIGATION

The investigation consists primarily of a study of the strain-aging characteristics of A.W.S. E6010 welds in A.S.T.M. A285 steel plate. Specimens were of the composite bead-on-plate type. After it had been established that such specimens were subject to strain-aging, the following factors were studied with regard to their individual influences on the severity of embrittlement:

1. The degree of prestraining.
2. The duration of storage at 70° F. after prestraining.
3. The duration of storage at 70° F. before prestraining.
4. The duration of storage at 212° F. following prestraining.
5. The temperature of the test employed for the evaluation of ductility.

In addition to this rather extensive work with E6010 welds on A285 plate, other types of mild steel and other classes of electrodes were employed in supplementary tests. The additional steels were welded only with the E6010 electrodes while the additional electrodes were applied only to the A285 plate. In all cases the specimens were found to exhibit strain-aging.

While the studies provide considerable information concerning the *conditions* under which strain-aging

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* These terms are used as defined by Epstein in reference 1.

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occurs in welds, they yield no conclusive indications concerning the *mechanism* of aging.

Since the data raised certain questions concerning the significance of the test used for the evaluation of ductility, it was necessary to devote considerable attention to this matter. Consequently, several sections of the paper are concerned with the nature of the notched-bend test.

## 3. SELECTION OF SPECIMEN

To evaluate ductility a version of the popular longitudinal notched-bend test was applied to bead-on-plate specimens. The reasons for the selection of this method are as follows:

1. Since it has been reported that the tendency toward strain-aging is more pronounced in coarse-grained than in fine-grained steels,[10] it was desired to test the welds in the columnar condition. This consideration suggested the use of the single-pass, bead-on-plate type of weld.

2. Such a weld is of additional interest since it resembles the final (and in many respects, the critical) pass of a multilayer butt weld.

3. A *longitudinal* test is of interest since it subjects *all regions* of the specimen to study by causing them to be strained in parallel. Such regions include the weld metal, the fusion line, the heat-affected zone and the unaffected plate.

4. The desirability of using a notched specimen was suggested by the fact that previous investigators have found that strain-age embrittlement tends to be more severe in the presence of a notch than in an unnotched specimen.[5, 7]

5. The preparation of a bead-on-plate specimen for the notch-bend test requires a minimum of expense and effort. No machining is required except for the milling of the notch.

## 4. THE BEND TEST AND PRESTRAINING

A typical bend test specimen is shown in a partially bent condition in Fig. 1.

Specimens were prepared in the following manner. The bead-on-plate weld was deposited along the major

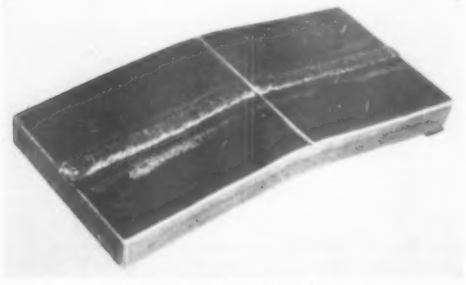


*Fig. 1 Bend-test specimen*

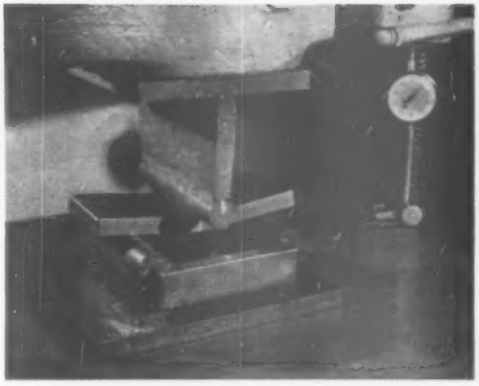


*Fig. 2 Fixtures used in bend test*

center line of the flame-cut 9 x 4 x $^3/_4$ in. blank. Within one day after welding, and prior to prestraining, a transverse groove was cut with a $^1/_8$ in. diameter convex milling cutter, thus forming a U-shaped notch of $^1/_{16}$ in. radius. The notch was cut across the entire width of the specimen to a depth 0.020 in. below the plate surface measured near the weld. (The total depth of weld penetration was approximately 0.110 in.) Except as otherwise noted, the notch was polished with 000 French emery paper.

In the bend test, the specimen was supported on 6 in. centers and was loaded as a simple beam with the notched weld in tension. The bending fixture is shown in Fig. 2. A radius of $^5/_8$ in. was provided at the supports and at the plunger. The cross-head speed during loading was 0.4 in. per minute.

Prestraining was accomplished in the same fixture and at the same cross-head speed. For the sake of convenience, prestraining was done at 70° F. (room temperature) whereas, for reasons disclosed in Sections 5 and 14, subsequent tests to destruction were performed at a lower temperature, usually −40° F.

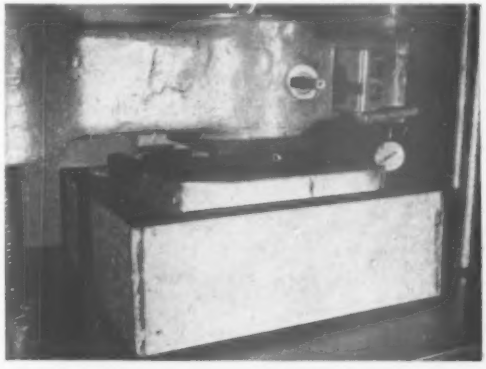


*Fig. 3 Setup for low-temperature bend tests in alcohol bath*

Testing at low temperatures was accomplished by locating the lower half of the bending fixture in a tank of alcohol supported by the lower platen of the testing machine (Fig. 3). The alcohol was maintained at the desired temperature by means of frequent additions of solid carbon dioxide.

Throughout the paper, ductility is reported in terms of the bend angle at fracture. These values include both plastic and elastic components of deformation (i.e., they describe the deformation just prior to the complete and sudden fracture of the specimen). Similarly, values of prestrain indicate the bend angles accomplished just prior to unloading.

Except as otherwise noted, specimens were stored at approximately 70° F. before and after prestraining.

## 5. THE TESTING TEMPERATURE

This section is devoted to considerations responsible for the decision to perform the bend tests at −40° F. It is concerned principally with the nature of the fracture process in the bend test, a subject which is considered further in Section 14.

It has been observed previously[11] and confirmed in the present work, that, under the conditions of the study, fracture tends to originate in the weld metal or at the fusion line. When the test is conducted at room temperature, the notch-sensitivity of the heat-affected-zone and of the parent plate may be sufficient to arrest the progress of the crack. Thus, complete fracture of the specimen may occur at a bend angle considerably larger than that at which the weld itself has completely failed.

If one wishes to determine the degree of deformation associated with the failure of the weld itself, he may obtain such an indication in several ways. He may, for instance, impose conditions which render the material outside of the weld so notch-sensitive that it is unable to arrest the progress of the crack once the latter has passed the boundaries of the weld. Such an effect may be attained by testing at a sufficiently low temperature. For this reason, most of the tests were conducted at −40° F., a temperature at which the complete fracture of the specimen coincided closely with that of the weld.

It will be noted in Section 14 that, under the conditions of the investigation, the bend angle at the complete fracture of the weld was nearly independent of testing temperature in the range from 70 to −105° F.

## 6. MATERIALS

The following types of mild steel were employed in the investigation, all in the form of $^3/_4$-in. plate:

1. A.S.T.M. A285-Grade C, Firebox Quality (a semikilled steel).
2. A.S.T.M. A201-Grade A, Firebox Quality, Aluminum-killed (a fully killed steel made with an aluminum addition of 1.15 lb. per ton).
3. Steel "E" ( a rimmed ship-plate steel).

These steels represent types which are widely employed in practice. All were used in the as-rolled condition.

The A201 plate is of particular interest since, in the absence of welding, it might be expected to exhibit superior resistance to strain-aging. It should be noted, however, that the aluminum addition of 1.15 lb. per ton was not as large as might be desired for this purpose.

The "E" steel is one of the "Navy project steels"[12, 13] which have been widely studied in recent years in the United States.

The A285 steel was obtained from two separate heats. The bulk of this material, four plates weighing one ton each, was taken from two consecutive slabs rolled from a single ingot. Henceforth, this portion will be termed the "second heat." The remainder (a single plate weighing one ton) represents another heat, and was used exclusively for the work described in Sections 8, 9 and 10. It will be termed the "first heat."

The chemical compositions of the steels are shown in Table 1* where for each material, two separate analyses are shown. The first represents samples obtained from near the plate surface while the second represents the mid-thickness region. The near-surface analysis has been included since it represents the region in which the bead-on-plate weld is deposited and in which subsequent failure is initiated in the bend test.

The standard tensile properties of the steels are shown in Table 2.

Four popular types of mild-steel welding electrodes were employed, namely, A.W.S. E6010, E6012, E6020

* For these analyses, the authors are indebted to R. C. Madden, Chief Metallurgist of the Kaiser Steel Co., Fontana, Calif.

**Table 1—Chemical Compositions of the Steels**

| | | *C* | *Mn* | *P* | *S* | *Si* | *Sn** | *Cu** | *Ni** | *Cr** | *V** | *Mo** | *N* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A285-C, 1st heat | NS† | 0.20 | 0.40 | 0.014 | 0.035 | 0.03 | ND† | 0.15 | 0.07 | 0.04 | ND† | 0.013 | 0.006 |
| | MT† | 0.20 | 0.40 | 0.014 | 0.036 | 0.03 | ND | 0.15 | 0.07 | 0.03 | ND | 0.012 | 0.006 |
| A285-C, 2nd heat | NS | 0.16 | 0.37 | 0.012 | 0.029 | 0.04 | 0.015 | 0.10 | 0.07 | 0.01 | 0.001 | 0.005 | 0.007 |
| | MT | 0.18 | 0.38 | 0.015 | 0.034 | 0.03 | 0.015 | 0.10 | 0.08 | 0.01 | 0.001 | 0.005 | 0.006 |
| A201-A†† | NS | 0.15 | 0.56 | 0.017 | ND | 0.21 | 0.015 | 0.12 | 0.07 | 0.02 | 0.001 | 0.002 | 0.006 |
| | MT | 0.12 | 0.55 | 0.015 | 0.029 | 0.22 | 0.015 | 0.08 | 0.08 | 0.04 | 0.001 | 0.001 | 0.006 |
| "E" steel | NS | 0.20 | 0.38 | 0.020 | 0.021 | 0.003 | 0.015 | 0.14 | 0.14 | 0.08 | 0.001 | 0.001 | 0.006 |
| | MT | 0.23 | 0.36 | 0.015 | 0.027 | 0.005 | 0.020 | 0.07 | 0.14 | 0.07 | 0.001 | 0.002 | 0.006 |

* Spectrographic analysis used for all determinations included in indicated rectangle.
† NS, MT and ND denote "near-surface," "mid-thickness" and "not determined," respectively.
†† Total aluminum = 0.03% (including 0.02 soluble, 0.01 insoluble).

**Table 2—Tensile Properties of the Steels**

| | *Yield point, 1000 psi.* | *Ultimate stress, 1000 psi.* | *Elongation at fracture, % in 8 in.* |
|---|---|---|---|
| A285-C, 1st heat | 40.4 | 61.3 | 27 |
| A285-C, 2nd heat | 35.7 | 56.5 | 32 |
| A201-A | 39.7 | 60.5 | 30 |
| "E" Steel* | 30.0 | 57.0 | 32 |

* Tensile values taken from reference 13.

and E6016. All electrodes were obtained from commercial stocks and were in good condition when used. The chemical compositions of the several varieties of weld metal are shown in Table 3.

## 7. WELDING PROCEDURE

Table 4 describes the welding conditions employed. Except in the case of the E6020 welds, the conditions are typical of those used in practice. The unusually low current used with the E6020 electrode was necessitated by the desire to produce a convex bead. It should also be noted that reverse polarity (electrode positive) was employed with this electrode. While either polarity is suitable, the E6020 class is more commonly used with straight polarity.

Prior to welding, the mill scale was removed from the plate along the path of the weld by means of grinding. During welding, specimens were supported on a steel-topped table, after which they were transferred immediately to a wood surface to cool in still air.

## 8. SOME PRELIMINARY INDICATIONS

This section describes some early exploratory work based on E6010 welds on the first heat of A285 plate.

One day after welding (and following the cutting of the notch) a series of specimens was subjected to various degrees of prestraining in the bending fixture. Three days after prestraining, the specimens were bent to fracture at −40° F.

The results of these tests are shown in Fig. 4 which describes the effects of prestraining on subsequent behavior. In this figure, the degree of prestraining (horizontal) is plotted against the additional deformation achieved in the test to fracture. It will be noted

**Table 4—Welding Conditions**

| | *E6010* | *E6012* | *E6016* | *E6020* |
|---|---|---|---|---|
| Current, amp. | 170 ± 5 | 185 ± 5 | 200 ± 7 | 152 ± 5 |
| Arc voltage | 25 ± 1 | 21 ± 1 | 20 ± 1 | 30 ± 1 |
| Arc speed, in./min. | 7.7 ± 0.4 | 7.6 ± 0.4 | 7.4 ± 0.4 | 7.6 ± 0.4 |
| Electrode burn-off rate, in./min. | 8.8 ± 0.4 | 9.4 ± 0.4 | 8.2 ± 0.4 | 8.9 ± 0.4 |
| Heat input* watt min./in. | 550 | 510 | 540 | 600 |
| Polarity | Reverse | Straight | Reverse | Reverse |

* Heat input defined as (current)(voltage)(arc speed)$^{-1}$.

that, in the absence of prestraining, specimens fractured at a bend angle of about 12°. The dashed line, then, represents the behavior which would be expected of prestrained specimens in the absence of strain-aging. Along this line, the sums of the horizontal and vertical coordinates are equal to the bend angle of the nonprestrained specimens. Since the actual data fall well below this line, strain-aging is indicated.

For illustrative purposes, consider the magnitude of the effect produced by prestraining to a bend angle of 2°. In the absence of prestraining, one would expect an additional bend angle of 10° in the final test (the value indicated by the dashed line). Actually, it is

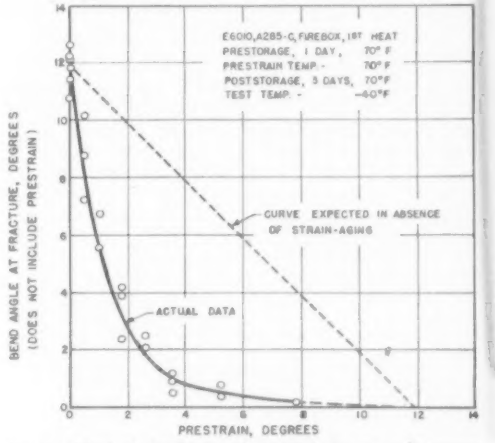



*Fig. 4 Effect of the degree of prestraining on subsequent behavior in bend test to fracture*
**E6010 welds, A285-C first heat plate**

**Table 3—Chemical Composition of Weld Metal**

| | *C* | *Mn* | *P* | *S* | *Si* | *Sn** | *Cu** | *Ni** | *Cr** | *V** | *Mo** | *N* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E6010, A285-C, 1st heat | 0.11 | 0.44 | 0.011 | 0.031 | 0.14 | ND | 0.14 | 0.08 | 0.01 | ND | 0.011 | 0.007 |
| E6010, A285-C, 2nd heat | 0.10 | 0.42 | 0.012 | 0.030 | 0.17 | ND | 0.09 | 0.04 | 0.03 | ND | 0.009 | 0.015 |
| E6010, A285-C, 2nd heat | 0.10 | 0.40 | 0.016 | 0.026 | 0.15 | 0.015 | 0.06 | 0.05 | 0.01 | 0.001 | 0.001 | 0.014 |
| E6010, A285-C, 2nd heat | 0.10 | 0.35 | 0.012 | 0.026 | 0.11 | 0.015 | 0.06 | 0.05 | 0.01 | 0.001 | 0.002 | 0.009 |
| E6010, A285-C, 2nd heat | 0.10 | 0.41 | 0.012 | 0.029 | 0.15 | 0.020 | 0.10 | 0.06 | 0.02 | 0.001 | 0.002 | 0.010 |
| E6010, A201-A | 0.11 | 0.45 | 0.014 | 0.027 | 0.15 | 0.015 | 0.05 | 0.05 | 0.03 | 0.001 | 0.002 | 0.010 |
| E6010, "E" steel | 0.12 | 0.38 | 0.015 | 0.020 | 0.10 | 0.015 | 0.09 | 0.08 | 0.04 | 0.001 | 0.001 | 0.009 |
| E6010, weld metal base | 0.10 | 0.40 | 0.016 | 0.029 | 0.15 | 0.012 | 0.14 | 0.05 | 0.02 | 0.002 | 0.007 | 0.014 |
| E6012, A285-C, 2nd heat | 0.12 | 0.29 | 0.016 | 0.032 | 0.13 | 0.025 | 0.08 | 0.07 | 0.02 | 0.001 | 0.001 | 0.021 |
| E6016, A285-C, 2nd heat | 0.11 | 0.43 | 0.015 | 0.026 | 0.34 | 0.015 | 0.06 | 0.08 | 0.02 | 0.001 | 0.001 | 0.014 |
| E6020, A285-C, 2nd heat | 0.14 | 0.34 | 0.018 | 0.025 | 0.07 | 0.020 | 0.07 | 0.06 | 0.02 | 0.001 | 0.001 | 0.018 |

* Spectrographic analysis used for all determinations included in indicated rectangle.

seen that an additional angle of only 3° was achieved.

It should be noted that in this work the notches were not polished but were left in the "as-machined" condition. Had they been polished, it is thought that somewhat greater values of bend angle would have been attained but that strain-aging would still have been evident. Since polished notches were employed in all subsequent work, caution is recommended in the direct comparison of subsequent results with those of Fig. 4.

## 9. STORAGE AT ROOM TEMPERATURE FOLLOWING PRESTRAINING

As just noted, Fig. 4 is based on tests in which only the degree of prestraining was varied. The specimens were prestrained at room temperature one day after welding and then were stored 3 days at room temperature before the final bend test at −40° F.

After evidence of strain-aging had been found under these conditions, it seemed reasonable to expect that even stronger tendencies might be obtained with altered conditions of storage. Accordingly, a series of specimens was tested in which the storage period after prestraining was varied. These specimens were similar to those of Fig. 4 in that they contained E6010 welds on the first A285 heat. They differed only in that polished notches were employed. One day after welding, these specimens were prestrained to a bend angle of 3°, a value selected after reference to the data of Fig. 4. They were then stored at room temperature for periods ranging from one-fourth of a day to 35 days after which they were subjected to a final test at −40° F.

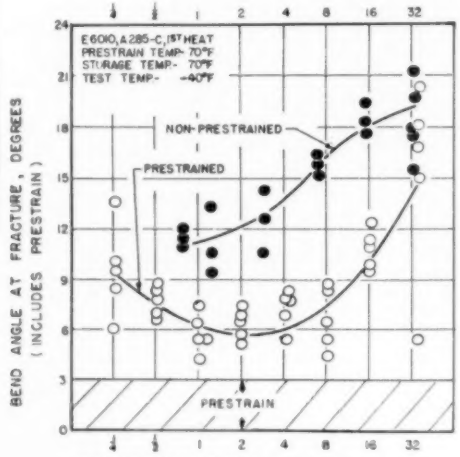

E6010, A285-C, 1ST HEAT
PRESTRAIN TEMP- 70°F
STORAGE TEMP- 70°F
TEST TEMP- -40°F
NON-PRESTRAINED
PRESTRAINED
PRESTRAIN
BEND ANGLE AT FRACTURE, DEGREES (INCLUDES PRESTRAIN)
STORAGE PERIOD AT ROOM TEMPERATURE, DAYS
FOR NON-PRESTRAINED SPECIMENS - FROM WELDING TO FRACTURE (I.E., TOTAL STORAGE PERIOD)
FOR PRESTRAINED SPECIMENS - FROM PRESTRAINING TO FRACTURE (ADD 1 DAY FOR TOTAL STORAGE PERIOD)

*Fig. 5 Effect of poststorage period at 70° F. on bend angle at fracture*

**E6010 welds, A285-C first heat**

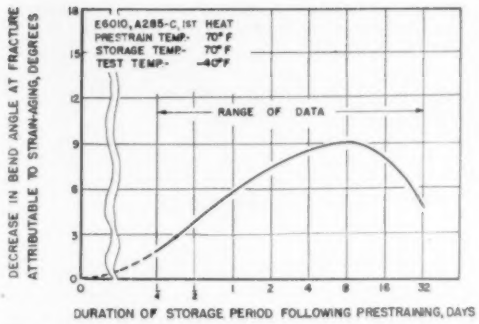

E6010, A285-C, 1ST HEAT
PRESTRAIN TEMP- 70° F
STORAGE TEMP- 70° F
TEST TEMP- -40°F
RANGE OF DATA
DECREASE IN BEND ANGLE AT FRACTURE ATTRIBUTABLE TO STRAIN-AGING, DEGREES
DURATION OF STORAGE PERIOD FOLLOWING PRESTRAINING, DAYS

*Fig. 6 Influence of poststorage time at 70° F. on the ductility loss attributable to strain-aging*

**E6010 welds, A285-C first heat. Obtained from a comparison of the curves of Fig. 5 for prestrained and nonprestrained specimens having equal total storage times**

The lower curve of Fig. 5 shows the results obtained with the specimens of this series. It will be seen that for storage periods of short duration an increase in storage time leads to a decrease in ductility. For storage periods greater than about 8 days, however, there is a pronounced reversal of this trend.

Interpretation of the results is, of course, complicated by the fact that, in the absence of prestraining, the duration of storage at room temperature is known to affect the results of notched-bend tests.[14, 15] For this reason, a comparison series of unstrained specimens was tested to evaluate the effect of storage time alone. The results, represented by the upper curve of Fig. 5, show, as expected, that considerable increases in ductility attend room-temperature storage.

To separate the effect of strain-aging from that of aging in the absence of prestraining, one must compare the upper and lower curves of Fig. 5. The results of such a comparison are shown in Fig. 6 which was derived from the smoothed curves of Fig. 5. Here the decrease in ductility attributable to strain-aging is plotted as a function of the duration of storage. It will be seen that for storage periods up to about 8 days there is a steady increase in the magnitude of the strain-aging effect. Further storage causes a decrease.

From Fig. 6 it is seen that strain-aging develops with considerable rapidity even at room temperature. The arbitrary selection of a storage period of 3 days for the exploratory work of Fig. 4 now appears to have been a fortunate choice.

The general shape of the curve in Fig. 6 (including the indications of overaging in the later stages) suggests that the mechanism may be of the precipitation-hardening type.

It is of interest to note that the embrittlement so apparent in Fig. 4 is ameliorated by prolonged storage at room temperature. This suggests that in practice strain-aging difficulties may be minimized by storage periods of similar or greater duration. Additional tests (Section 18) indicate that amelioration is accelerated at higher temperatures.

## 10. EFFECT OF STORAGE TIME BEFORE PRESTRAINING

As has just been noted in Fig. 5, high values of ductility were exhibited by specimens prestrained one day after welding and tested a month after prestraining. One now wonders if similarly high values would result if the same *total* storage period were employed but if prestraining were performed at a later stage in the period.

To answer this question, another series of specimens was prepared. After welding, and before prestraining, these specimens were stored at room temperature for periods ranging from less than one day to nearly 32 days. Each specimen was then subjected to a prestrain of 3° after which it was stored at room temperature until a *total* storage period of 32 days had been reached. At the end of this time the specimens were bent to fracture at −40° F. The portions of the total storage period which precede and which follow prestraining will henceforth be termed the *"prestorage"* and *"post-storage"* periods, respectively.

The results obtained in these tests are represented in Fig. 7. On the basis of this figure, the following observations may be made:

1. As expected, the results obtained with the specimens subjected to a poststorage period of 32 days (after very brief prestorage) are in agreement with those for the corresponding condition in Fig. 5.

2. While this treatment produces the greatest ductility in Fig. 5, it is the condition of least ductility in Fig. 7. According to the latter figure, the longer the prestorage period, the greater is the bend angle at the end of 32 days.

The second observation is of practical interest since it indicates that, after a month or more of storage, ductility may be expected to be of a high order regardless of the time at which any prestraining may have occurred. Thus it appears that any difficulties which might arise from strain-age embrittlement are to be expected soon after welding. The duration of the danger period might, of course, be expected to increase under conditions of low-temperature storage.

Incidentally, it is suggested by the results of Figs. 5 and 7 that in laboratory studies of the strain-aging welds, careful attention must be given to the duration of storage before testing. Similarly, as will be seen in Section 19, the temperature of the specimen should be controlled during any machining operations which follow welding.

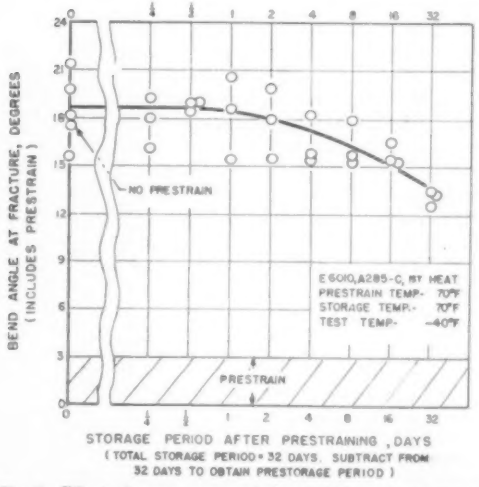



*Fig. 7 Effect of prestorage period at 70° F. on bend angle at fracture for a total storage period of 32 days*
E6010 welds, A285-C first heat

## 11. WELDS ON OTHER STEELS

Having seen that E6010 welds on the first heat of A285 plate exhibit strain-aging, one wonders whether similar behavior would be displayed by welds on other types of plate.

To answer such a question, tests were performed on three other steels. These materials, described in Section 6, included a second heat of A285, A201 and the "E" steel. Except for the fact that the notches were polished in this work, the procedure was similar to that associated previously with Fig. 4. As before, specimens were subjected to various degrees of prestraining one day after welding and were tested at −40° F. three days after prestraining.

The behaviors of the specimens are shown in Figs. 8, 9 and 10. In each case strain-aging is apparent.

It is of particular interest to note that welds on the fully killed plate are as sensitive to strain-aging as are those on the semikilled and rimmed varieties. Such a similarity is perhaps not surprising since, under the conditions employed, it is believed that the bend test measures the ductility of the weld itself. As seen in Table 3, the composition of the weld is little effected by the nature of the plate.

It should be noted that, although the A201 plate is described by its producer as "aluminum-killed," the aluminum content (0.03%) is not as great as might be desired. Had it been greater, it is possible that the plate might have been able to arrest the propogation of fracture at −40° F. It is also conceivable that sufficient pickup of aluminum might have occurred in the weld to affect its tendency toward strain-aging.

Comparison of Figs. 4 and 8 reveals that the bend angle values in the nonprestrained condition are considerably greater in the case of the second heat of A285 plate than in the first. The difference is attributed, in part at least, to the fact that unpolished notches were employed in the case of the first heat, whereas, polishing was employed in all subsequent work.

## 12. WELDS ON A WELD METAL BASE

To further assess the influence of the base material on the strain-aging characteristics of E6010 welds, tests

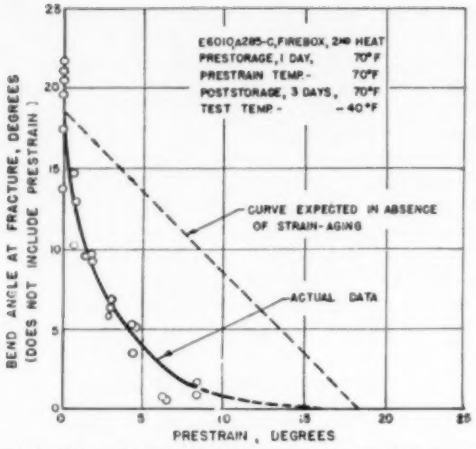

E6010(A285-C,FIREBOX, 2ND HEAT
PRESTORAGE, 1 DAY, 70°F
PRESTRAIN TEMP.- 70°F
POSTSTORAGE, 3 DAYS, 70°F
TEST TEMP.- -40°F
CURVE EXPECTED IN ABSENCE OF STRAIN-AGING
ACTUAL DATA
BEND ANGLE AT FRACTURE, DEGREES (DOES NOT INCLUDE PRESTRAIN)
PRESTRAIN, DEGREES

*Fig. 8 Effect of the degree of prestraining on subsequent behavior in bend test to fracture*
E6010 welds, A285-C second heat plate

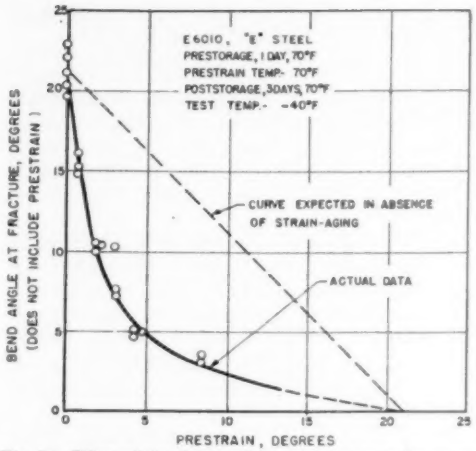



*Fig. 10 Effect of the degree of prestraining on subsequent behavior in bend test to fracture*
E6010 welds, "E" steel

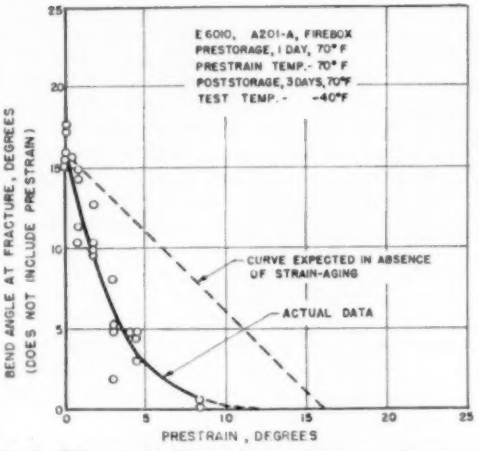

E6010, A201-A, FIREBOX
PRESTORAGE, 1 DAY, 70° F
PRESTRAIN TEMP.- 70° F
POSTSTORAGE, 3 DAYS, 70°F
TEST TEMP.- -40°F
CURVE EXPECTED IN ABSENCE OF STRAIN-AGING
ACTUAL DATA
BEND ANGLE AT FRACTURE, DEGREES (DOES NOT INCLUDE PRESTRAIN)
PRESTRAIN, DEGREES

*Fig. 9 Effect of the degree of prestraining on subsequent behavior in bend test to fracture*
E6010 welds, A201-A plate

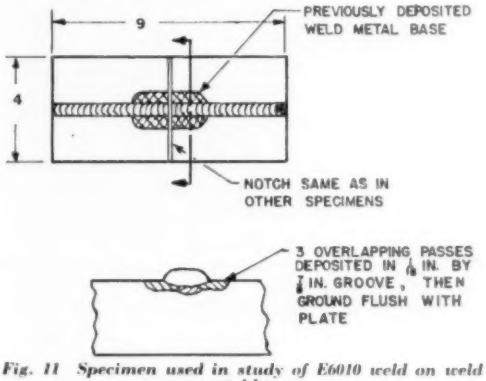

9
4
PREVIOUSLY DEPOSITED WELD METAL BASE
NOTCH SAME AS IN OTHER SPECIMENS
3 OVERLAPPING PASSES DEPOSITED IN 1/8 IN. BY 1/4 IN. GROOVE, THEN GROUND FLUSH WITH PLATE

*Fig. 11 Specimen used in study of E6010 weld on weld metal base*

were performed on welds deposited on a weld-metal base.

Using plate from the second A285 heat, specimens were prepared in the following manner. A groove $^1/_{16}$ in. deep by $^7/_8$ in. wide was milled along the central $3^1/_2$ in. of the longitudinal center line of the standard $^3/_4$ x 4 x 9 in. blank (Fig. 11). This groove was then filled with a single layer of E6010 weld metal consisting of three overlapping beads. Later the reinforcement was ground flush with the plate surface with the result that the blank was again geometrically similar to the standard blank. It was distinguished, however, by the fact that the central portion of its surface consisted of weld metal. A standard E6010 bead-on-plate weld was then deposited in the usual manner.

After welding and notching, the specimens prepared in this fashion were divided into two groups. The first group was not prestrained, whereas, one day after welding, the second group was prestrained to a bend angle of $4^1/_2$ degrees. Four days after welding, the specimens of each group were fractured at −40° F.

The results of the tests are shown in Table 5 where the now familiar indications of strain-aging are apparent. As in the previous section, it must be concluded

**Table 5—Behavior of E6010 Welds on E6010 Base**

| *Prestrain,°* | *Bend angle at fracture,° (includes prestrain)* |
|---|---|
| 0 | 14.7 |
| | 14.5 (15.3 av.) |
| | 16.7 |
| $4^1/_2$ | 6.0 |
| | 6.9 (6.7 av.) |
| | 6.0 |
| | 7.9 |

that the strain-aging susceptibility of the weld is little affected by the nature of the plate upon which it is made.

## 13. TESTS WITH E6012 AND E6020 ELECTRODES

In the preceding sections it has been seen that, regardless of the plate material, bead-on-plate E6010 welds are susceptible to strain-aging. One wonders now if welds deposited with other commonly used electrodes would exhibit similar behavior. Such a question is the principal concern of this section which deals with tests on E6012 and E6020 welds in the second heat of A285 plate. In a later section E6016 welds will be considered.

The welding conditions employed with the E6012 and E6020 electrodes are described in Table 4. It will be noted that the rates of heat input (measured in terms of the arc energy per unit length of weld) did not differ greatly from the value employed previously with the E6010 welds.

Methods of specimen preparation and testing were similar to those described previously for E6010 welds in Section 11. One day after welding, the specimens were subjected to various degrees of prestraining and three days later they were fractured at −40° F.

The results of the tests are shown in Figs. 12 and 13. Here it may be seen that, with regard to strain-aging, the behaviors of the E6012 and E6020 welds are qualitatively similar to that exhibited by the E6010 variety.

Whatever may be the mechanism of strain-aging in E6010 welds, it would seem likely that the same mechanism affects the other types as well. (It will be seen later than E6016 welds also exhibit strain-aging.) Thus, one suspects that susceptibility to strain-aging may be characteristic of arc welds in mild steel regardless of the type of electrode or plate employed. Since, however, welds on plate of high aluminum content have not as yet been studied, it is possible that they may constitute an exception.

At this point it may be of interest to speculate on how one might proceed if he wished to produce welds which, without subsequent treatment, would be resistant to strain-aging. Let us assume for this purpose that either carbon or nitrogen is involved in the mechanism. It would probably be difficult to produce welds having substantially lower carbon and nitrogen contents. It might be possible, however, to reduce the strain-aging sensitivity by incorporating stabilizing elements in the welding wire or in the coating. Such additions would be intended to enter into the weld metal and to reduce the carbon and nitrogen contents of the ferrite by fixing these elements as carbides and nitrides.

Another observation, not related to strain-aging, may be based on Figs. 12 and 13. Comparison of these figures with Fig. 8 reveals that the ductility of the E6012 and E6020 welds in the nonprestrained condition is inferior to that exhibited by the E6010 type. The average bend angle values are, respectively, 7, 14 and 18°. The low ductility of the E6012 welds is especially striking.

That the ductility of the E6012 variety should be lower than that of the other types is not surprising since in specifications for mild-steel electrodes (A.W.S. A5.1; A.S.T.M. A233) lower ductility is permitted in E6012 deposits than in those of the other types. From this viewpoint, however, the intermediate ductility of the E6020 welds in the present tests is not consistent with the order of the minimum values permitted in these specifications. It should be remembered that in the present work the E6020 electrodes were used with a lower welding current than would generally be employed in practice.

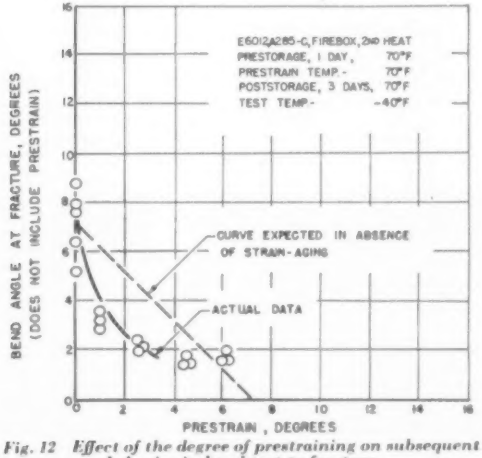

E6012A285-C, FIREBOX, 2ND HEAT
PRESTORAGE, 1 DAY, 70°F
PRESTRAIN TEMP - 70°F
POSTSTORAGE, 3 DAYS, 70°F
TEST TEMP - -40°F
CURVE EXPECTED IN ABSENCE OF STRAIN-AGING
ACTUAL DATA
BEND ANGLE AT FRACTURE, DEGREES (DOES NOT INCLUDE PRESTRAIN)
PRESTRAIN, DEGREES

*Fig. 12 Effect of the degree of prestraining on subsequent behavior in bend test to fracture*
E6012 welds, A285-C second heat plate

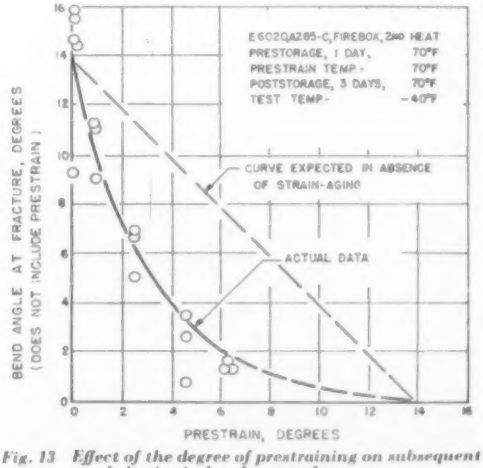

E6020A285-C, FIREBOX, 2ND HEAT
PRESTORAGE, 1 DAY, 70°F
PRESTRAIN TEMP - 70°F
POSTSTORAGE, 3 DAYS, 70°F
TEST TEMP - -40°F
CURVE EXPECTED IN ABSENCE OF STRAIN-AGING
ACTUAL DATA
BEND ANGLE AT FRACTURE, DEGREES (DOES NOT INCLUDE PRESTRAIN)
PRESTRAIN, DEGREES

*Fig. 13 Effect of the degree of prestraining on subsequent behavior in bend test to fracture*
E6020 welds, A285-C second heat plate

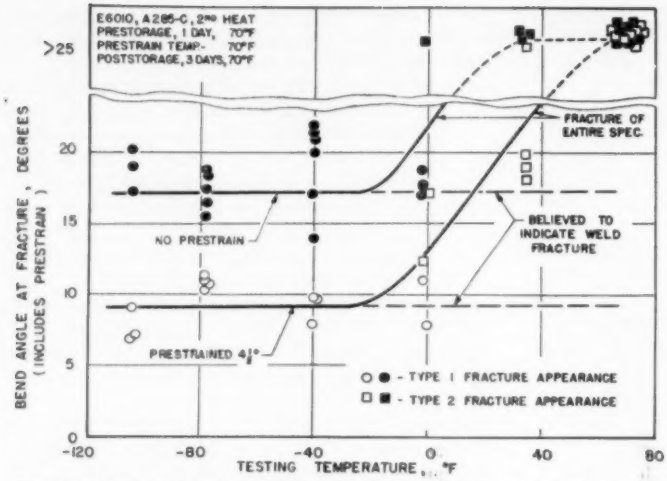



*Fig. 14 Influence of testing temperature and prestraining on behavior in bend test*

E6010 welds, A285-C second heat

## 14. EFFECT OF TESTING TEMPERATURE, A285 PLATE

The results presented up to this point have been based on tests performed at −40° F. While it is now clear that strain-aging is revealed under these conditions, one wonders what indications might attend the use of other testing temperatures. For this reason, tests were run under the conditions described in the following paragraph.

Two groups of specimens containing E6010 welds on the second heat of A285 plate were welded, notched, and polished in the usual fashion. The specimens were then divided into two groups, the first of which was subjected to no prestraining while, one day after welding, the specimens of the second group were prestrained to an angle of 4½°. Four days after welding both sets of specimens were subjected to bend tests at temperatures ranging from 70 to −105° F. The results of these tests are shown in Fig. 14 in which the values of bend angle at fracture (including prestrain) are plotted against temperature.

It is clear from Fig. 14 that at temperatures from −105 to −40° F. a considerable strain-aging effect characterizes the prestrained specimens. In this range the magnitude of the effect appears to be nearly independent of the testing temperature. Thus, it would appear that the strain-aging indications obtained in the previous work at −40° F. might have been obtained at lower temperatures as well.

Interpretation of the high-temperature results of Fig. 14 requires consideration of the manner in which specimens fracture in the notched-bend test. As noted in Section 5, it is believed that, under the conditions employed, fracture is initiated in the weld metal (the usual case) or at the fusion line. At this stage several small, apparently independent cracks may appear. Later, as a result of further bending, a major crack develops and extends across the weld. Its further progress then may proceed in either of two ways.

Mode 1: If the testing temperature is sufficiently low, the toughness of the heat-affected zone and of the remainder of the plate is not sufficient to arrest the progress of the crack. As a result, the fracture of the entire specimen occurs at a bend angle nearly coinciding with that for the complete fracture of the weld.

Mode 2: At higher temperatures the notch-resistance of the plate, especially in the refined region of the heat-affected zone, may be sufficient to stop the progress of the crack. In such cases the complete fracture of the specimen (and also the attainment of maximum load) may occur at a bend angle greater than that characterizing the fracture of the weld itself.

By examination of a fractured specimen it is usually possible to distinguish which of these two modes of fracture has occurred. Figures 15 and 16 illustrate the typical appearances of specimens tested at −40 and at 32° F., respectively. The appearance of the specimen in Fig. 15 results from the first mode of fracture, while that of Fig. 16, by virtue of the excess opening at the weld, indicates the second type.

We now return to consideration of Fig. 14. From

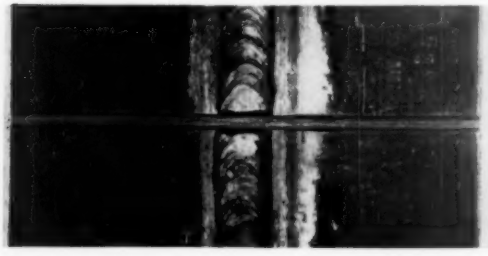


*Fig. 15 Typical crack appearance at fracture in specimens bent at −40° F. Type 1 appearance*

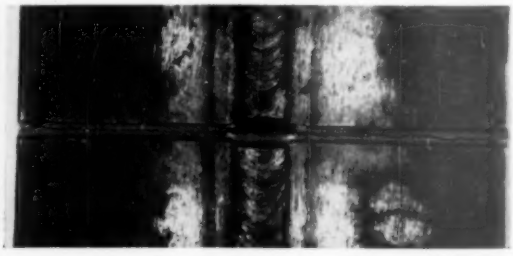


*Fig. 16 Typical crack appearance at fracture in specimens bent at 32° F. Type 2 appearance*

the appearance of the fractured specimens, it is believed that all those tested at −105, −75 and −40° F. fractured according to the first mode. Of those tested at the next higher temperature, −5° F., the majority failed in the first mode, the remainder in the second. At the two higher temperatures, 32 and 70° F., all fractures were of the second sort. It is concluded, therefore, that in Fig. 14 the tests at the higher temperatures fail to indicate the ductility of the weld itself. Such tests merely reflect the high notch-resistance of the material outside of the weld.

## 15. ROOM-TEMPERATURE TESTS

To supplement the data of Fig. 14, it was desired to determine the bend angle characterizing the fracture of the weld alone at the upper temperatures. This was accomplished at 70° F. by means of interrupted tests which allowed frequent inspection of the specimen during testing. The results of this work are represented in Table 6 which shows the bend angles required to produce the first stages of cracking in the weld, the complete fracture of the weld and the fracture of the entire specimen. The first stages of fracture were observed at 50 power magnifications. Since a total time no greater than 15 min. was required for the fracture of the weld in each test, little strain-aging is believed to have occurred during testing and inspection.

It will be seen in Table 6 that strain-aging is clearly indicated at 70° F. if one takes as criterion the complete fracture *of the weld*. The aging of the weld is obscured, however, if only the fracture of the entire specimen is considered.

**Table 6—Study of Fracture Process at 70° F. E6010—A 285 Second Heat—Storage at 70° F.**

| | *Bend angle values,° (including prestrain)* | | | |
|---|---|---|---|---|
| *Prestrain,° (one day after welding)* | *First suspicion of crack** | *Crack length reaches 0.05 in.* | *Complete fracture of weld* | *Complete fracture of specimen* |
| 0 | 12 | 13 | 18 | 65 |
| 0 | 6 | 15 | 20 | >46 |
| 0 | 11 | 15 | 18 | 44 |
| 4½ | 6 | .. | 8 | 48 |
| 4½ | 6 | .. | 7 | >65 |
| 4½ | 6 | .. | 9 | >57 |
| 4½ | 6 | .. | 9 | >65 |

* First stages of cracking studied at 50 × magnification.

From Table 6 it may also be seen that the complete fracture of the weld at 70° F. occurs at essentially the same bend angle as that which is required for the fracture of the entire specimen at the lower temperatures of Fig. 14. (This is the case for both the prestrained and nonprestrained conditions.) Thus, the bend angle values for the complete fracture of the weld appear to be nearly independent of temperature over the entire range from −105 to 70° F.

On this basis, two separate curves have been drawn for each condition in Fig. 14. The horizontal paths are believed to represent the complete fracture of the weld itself, whereas, the S-shaped curves refer to the fracture of the entire specimen. According to this interpretation of the data, the "transition temperatures" for the latter curves refer to an abrupt change in the notch-sensitivity of the material outside of the weld. At such temperatures the mode of fracture changes from the first type to the second and the appearance of the fracture changes from that of Fig. 15 to that of Fig. 16.

Another observation which may be based on Table 6 concerns the resistance of the weld to initial cracking and to the subsequent extension of cracks across the weld. It is seen that the first small cracks appear in the prestrained specimens at an average angle of 6° (including prestrain), whereas they appear in the nonprestrained specimens at an average angle of 10°. In addition, it appears that the further increase in bend angle required for the complete fracture of the weld is considerably lower in the case of the prestrained specimens (2°) than for the other group (9°). Thus, it would seem that strain-aging affects the weld's ability to resist crack propagation as well as to resist crack initiation.

Since considerable uncertainty attends the detection of the first small cracks on the bend test, there may be reasonable doubt concerning the validity of the corresponding entries in Table 6. Difficulty arises from the fact that a pronounced "orange peel" appears on the surface of the weld at small bend angles. It is difficult to distinguish a small crack from the orange peel markings.

## 16. EFFECT OF TESTING TEMPERATURE, A201 PLATE

Tests similar to those represented in Fig. 14 for E6010 welds on semikilled A285 plate were also performed on E6010 welds on the fully killed A201 plate. The results shown in Fig. 17 are in all respects similar to those of Fig. 14. Again strain-aging of the weld is clearly evident. With regard to the influence of testing temperature, the comments previously based on Fig. 14 are again applicable.

With some of the specimens exhibiting mode 2 fractures at −5° F. and at 32° F., it was possible to stop the tests immediately after the fracture of the weld itself (as indicated by a sudden, marked drop in load). The bend angles for this condition, shown by triangles in Fig. 17, are seen to be very nearly equal to those required for the fracture of the entire specimen at lower temperature. (In these cases, the fracture of the entire specimen would, of course, have required a further increase in bend angle.) Thus, the data of Fig. 17 confirm the interpretation of the "transition" temperature just given in Sections 14 and 15.

## 17. CONCERNING THE PRESTRAINING TEMPERATURE

This section deals with a question concerning interpretation of the data which in the preceding pages have

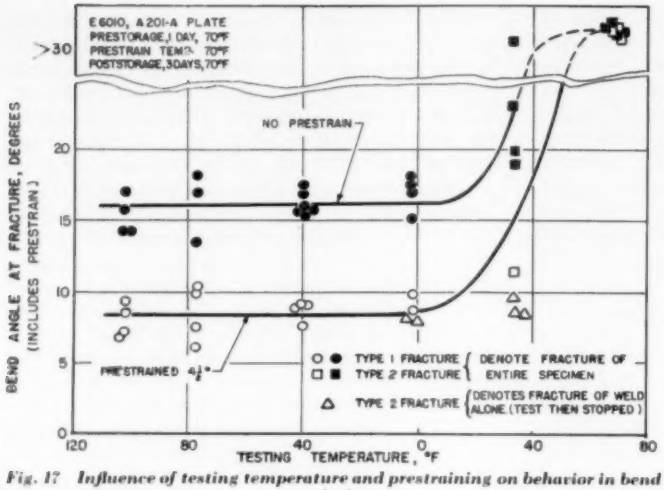



*Fig. 17 Influence of testing temperature and prestraining on behavior in bend test*

E6010 welds, A201-A plate

been said to denote strain-aging. The question concerns the use of a prestraining temperature (70° F.) higher than that used in subsequent tests to fracture (−40° F.).

To justify this procedure (which was used for the sake of convenience), tests were performed on a series of specimens prepared with E6010 welds on A285 plate of the second heat. The specimens were notched and polished in the usual manner after which they were divided into three groups. These groups were then prestrained and fractured under the various conditions ascribed to Groups 1, 2 and 3 in the legend of Fig. 18. The results of the tests are shown in the same figure which also includes some related data (Groups A and B) abstracted from Fig. 8.

Groups A and B differ from each other only in that the specimens of the latter group were prestrained 4½ degrees one day after welding while those of the former were not prestrained. In each case, the test to fracture was performed at −40° F. four days after welding. The lower ductility of the prestrained specimens (Group B) has in previous sections been attributed to strain-aging.

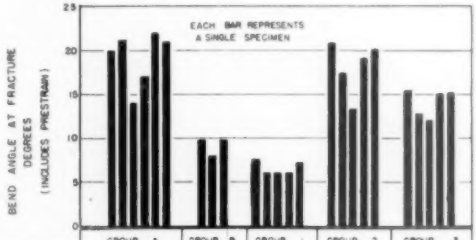
But it may be asked, "can this lower ductility not be attributed in part at least to the fact that prestraining was done at 70° F., whereas, the test to fracture was performed at −40° F.?" Would a similar decrease in ductility have occurred if prestraining had been done at −40° F.? Such a question may be answered by comparing the behavior of the Group 1 specimens with those of Group B in Fig. 18. The treatments accorded these groups differ only with respect to the prestraining temperature. It will be seen from Fig. 18 that the bend angles obtained with the Group 1 specimens (prestrained at −40° F.) are somewhat lower than those of Group B. Thus, the magnitude of the strain-aging effect is, if anything, greater when prestraining is done at −40° F. The magnitude of the effect is then indicated by a comparison of Group 1 and Group A.

Overlooking this evidence for the moment, the question may be put in a different way. Is it not possible that prestraining at 70° F. exhausts a greater proportion of the specimen's residual ductility than does the same degree of prestraining at −40° F.? This question may be answered directly by comparing the results for Groups 2 and 3 in Fig. 18. Each of these groups was fractured at −40° F. directly after prestraining. They differed only in that the specimens of Group 2 were prestrained at 70° F. while those of Group 3 were prestrained at −40° F. From Fig. 18, it will be seen that the values of bend angle at fracture are somewhat lower for the Group 3 specimens than for those of Group 2. Thus, it is seen that the phenomena termed strain-aging in previous sections cannot be attributed, even in part, to the use of a prestraining temperature which was higher than the temperature used in the test to fracture.

The behaviors exhibited in Fig. 18 are, of course, not unexpected. The literature on the influence of prestraining temperature on subsequent ductility has recently been reviewed and summarized by Sachs.[16] This evidence indicates that plastic deformation at a low temperature produces a greater degree of strain-hardening than does the same deformation at a higher temperature.

## 18. STORAGE AT 212° F. AFTER PRESTRAINING

It has been shown in Fig. 5 that prestrained specimens become increasingly embrittled in the early stages of




| | GROUP A | GROUP B | GROUP 1 | GROUP 2 | GROUP 3 |
|---|---|---|---|---|---|
| PRESTRAIN, DEGREES | 0 | 4½ | 4½ | 4½ | 4½ |
| TIME, WELD TO PRESTRAIN | | 1 DAY | 1 DAY | 1 DAY | 1 DAY |
| PRESTRAIN TEMP., °F | | 70 | −40 | 70 | −40 |
| PRESTRAIN TO FRACTURE | | 3 DAYS, 70°F | 3 DAYS, 70°F | 1 HOUR | 1 MINUTE |
| FRACTURE TEMP., °F | −40 | −40 | −40 | −40 | −40 |
| TIME, WELD TO FRACTURE | 4 DAYS | 4 DAYS | 4 DAYS | 4 DAYS | 4 DAYS |

*Fig. 18 Influence of prestraining temperature on subsequent behavior in bend test at −40° F.*

E6010 welds, A285-C second heat

subsequent storage at 70° F. A minimum value of ductility is reached in several days, after which the ductility improves. One would expect that similar changes might be produced at other storage temperatures and that an increase in temperature might accelerate the change. With this in mind, it was decided to conduct tests similar to those of Fig. 5 employing a storage temperature of 212° F. after prestraining.

The specimens, containing E6010 welds on A285 plate of the second heat, were prepared in the usual fashion. One day after welding they were divided into two groups. All specimens of the first group were prestrained to an angle of $4^1/_2$° while those of the second were not prestrained. Immediately thereafter the specimens were placed in boiling water to age for times ranging from $^1/_2$ to 16 hr. Upon removal, each specimen was quenched to 70° F. and within the next 6 hr. was fractured at −40° F.

The results of these tests have been plotted in Fig. 19 in the manner used previously in Fig. 5.

The upper curve in Fig. 19 represents the changes which affect the nonprestrained specimens. As might be expected, there is a gradual increase in ductility, qualitatively similar to that achieved more slowly at room temperature.

The lower curve represents the behavior of the prestrained specimens. As before, strain-aging is clearly evident. Again the shape of the curve is similar to that obtained at 70° F. In the early stages of aging, the ductility is seen to decrease. A minimum value is reached in approximately 1 hr. after which the ductility increases.

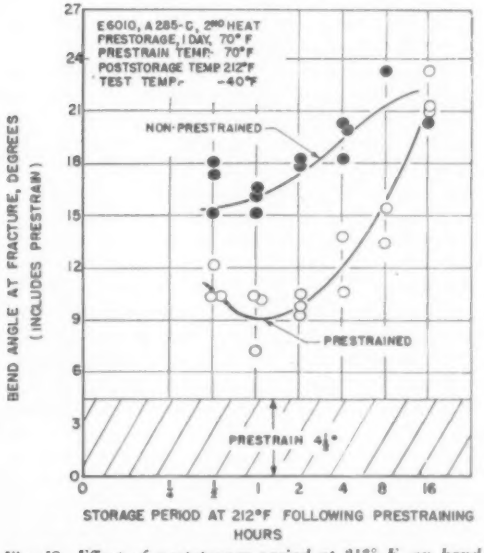



*Fig. 19 Effect of poststorage period at 212° F. on bend angle at fracture*

E6010 welds, A285-C second heat. (Data not shown for specimens exhibiting Type 2 fracture appearance. See text)

The strain-aging effect, indicated in Fig. 19 by the difference between the upper and lower curves, reaches its peak after about 2 hr. It is of interest to compare this time with the corresponding period, 8 days, required at 70° F. The ratio of the times, approximately $^1/_{100}$, is consistent with the fact that in this range of temperature the rates of many types of reactions are known to be doubled by an increase in temperature of approximately 20° F.

An observation concerning the mode of fracture may also be based upon the 212° F. tests. In all work reported prior to this section, testing at −40° F. caused the fracture of the entire specimen to coincide with the complete fracture of the weld. In the 212° F. tests, however, a departure from this behavior was noted. It was observed that specimens aged less than 2 hr. behaved in the normal manner. In the case of those aged 2 hr. or longer, however, the remainder of the specimen sometimes failed to break immediately after the fracture of the weld. The data in such cases have been excluded from Fig. 19. In these cases, it was possible to estimate the bend angles at which weld fracture had occurred. The addition of such data (not shown in Fig. 19) do not significantly affect the curves which have been drawn.

To account for the behavior just noted, it must be presumed that aging at 212° F. in some way improves the notch resistance of the heat-affected zone and of the parent plate in addition to affecting the properties of the weld metal.

## 19. TESTS ON E6016 WELDS

In Section 10, it was noted that prolonged storage at room temperature before prestraining tends to minimize the severity of subsequent strain-age embrittlement. This suggests that some unidentified beneficial change occurs during storage. Since it is known that hydrogen may escape from the supersaturated weld metal at room temperature, it is of interest to examine the possibility that the hydrogen content of the weld may affect its resistance to strain-aging.

Accordingly, a series of welds was made on A285 (second heat) plate with "low-hydrogen" electrodes of the E6016 class. The results of the tests are shown in Fig. 20. The scatter is so great unfortunately, especially for the nonprestrained condition, that the usefulness of the data is in doubt.

Better evidence concerning the behavior of E6016 welds was furnished by a second series of tests. In this work specimens were prestrained to a bend angle of $4^1/_2$° and then were aged for various periods at 212° F. The procedure was in all respects similar to that described in the preceding section for E6010 specimens. The results of these tests are shown in Fig. 21.

Figure 21 indicates that the E6016 welds are unmistakably susceptible to strain-aging. Comparison with Fig. 19 reveals further that the severity of strain-aging is not greatly different from that obtained with E6010

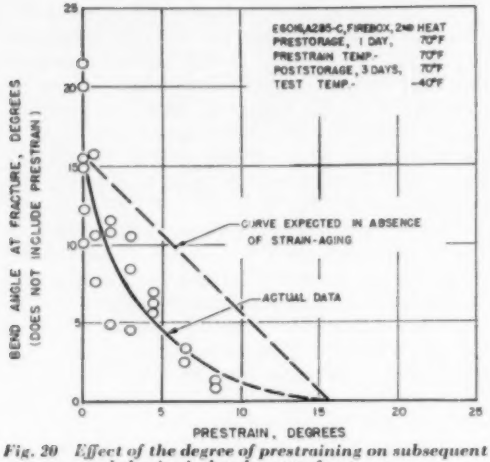

E6016, A285-C, FIREBOX, 2ND HEAT
PRESTORAGE, 1 DAY, 70°F
PRESTRAIN TEMP- 70°F
POSTSTORAGE, 3 DAYS, 70°F
TEST TEMP.- -40°F
CURVE EXPECTED IN ABSENCE OF STRAIN-AGING
ACTUAL DATA
BEND ANGLE AT FRACTURE, DEGREES (DOES NOT INCLUDE PRESTRAIN)
PRESTRAIN, DEGREES

*Fig. 20 Effect of the degree of prestraining on subsequent behavior in bend test to fracture*

E6016 welds, A285-C second heat plate

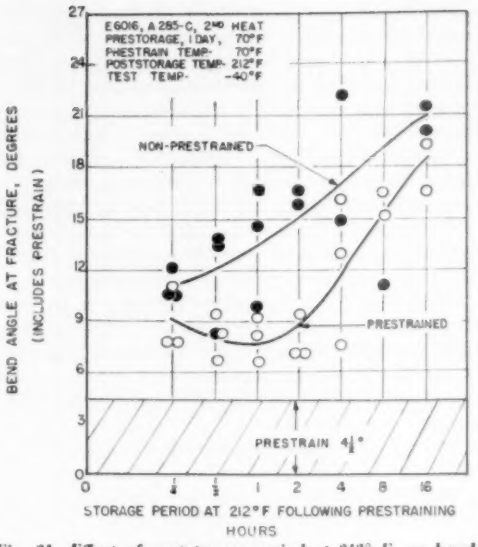



*Fig. 21 Effect of poststorage period at 212° F. on bend angle at fracture*

E6016 welds, A285-C second heat. (Data not shown for specimens exhibiting Type 2 fracture appearance. See text)

electrodes. It must be concluded, then, that the low-hydrogen content* of the E6016 welds does not insure resistance to strain-aging. Inferentially, it appears difficult to explain the beneficial effects of prolonged prestorage (Section 10) on the basis of hydrogen content. In this connection it may be noted that Hensel and Larsen[4] found atomic hydrogen welds to be less susceptible to strain-aging than oxyacetylene welds even when the former contained a greater nitrogen content.

Aside from the question of strain-aging, another observation of interest may be based on comparison of Figs. 19 and 21. This observation concerns the well-known tendency for the ductility of E6010 welds to improve with time during storage at room temperature and at moderately elevated temperatures. Some authorities believe that the improvement must be attributed to the escape of hydrogen which occurs during storage.[17–19] In this connection it is of interest to note that during storage at 212° F. both the E6010 and the E6016 welds improve with time (Figs. 19 and 21). Furthermore, the ductility of the E6016 welds (low-hydrogen) is, if anything, somewhat lower than that of the E6010 (high-hydrogen) variety at all stages of aging. Such an observation would seem difficult to reconcile with any simple theory ascribing the improvement in ductility to a reduction in *total* hydrogen content during storage. If hydrogen indeed plays an important role, it can scarcely be the total content which is decisive, but instead some fraction of the total.[11]

## 20. CONCERNING THE FRACTURE ORIGIN AND THE SITE OF STRAIN-AGING

In the preceding pages there have appeared indications that the fracture origin in the bend tests, and inferentially the site of strain-aging, is located in the weld itself. In this section, we shall deal with a question concerning the significance of such indications. Does the location of the fracture origin reflect an inherent property of the weld or can it be explained by geometrical considerations alone?

It must be recognized that the weld reinforcement on the specimen causes the notch to be deeper at the weld than in other regions. In the bend test this difference in depth might be expected to produce a maximum strain concentration at the weld and thus to influence the location of the fracture origin.

To explore this possibility, tests were performed on notched specimens of a type containing no weld but machined to simulate the shape of the standard bead-on-plate specimen. It was found under these conditions that the fracture, even in the absence of a weld, still originated at the "reinforcement." The tests, however, revealed no indications of strain-aging, values of bend angle at fracture being unaffected by prestraining.

To further clarify the situation, a series of welded specimens was tested after the reinforcement had been removed by machining. These specimens, containing E6010 welds on plate of the second A285 heat, were notched in the usual manner to a depth 0.020 in. below the surface of the plate. They were then divided into two groups. The first was not prestrained while the second was prestrained $4\frac{1}{2}°$ one day after welding. Four days after welding the specimens were fractured at −40° F. The results of the test are shown in Table 7.

It is seen from Table 7 that removal of the reinforcement causes a considerable increase in the values of bend angle at fracture. (Compare with Fig. 8.)

* While hydrogen contents were not measured, it is presumed that those of the E6016 welds were low. This class of electrode was developed specifically for such a purpose.

**Table 7—Behavior of Notched Specimens after Removal of Weld Reinforcement by Machining. E6010—A285 Second Heat**

| *Prestrain, degrees (at 70° F.)* | *Bend angle at fracture, degrees (at −40° F.)* | *Fracture type (as defined in Section 14)* |
|---|---|---|
| 0 | 34 | 1 |
| 0 | 34* | 2 |
| 0 | 33* | 2 |
| 4½ | 18 | 1 |
| 4½ | 20 | 1 |
| 4½ | 22 | 1 |

* Indicates bend angle at complete fracture of weld as revealed by abrupt drop in load.

This increase is presumably induced by alleviation of the strain concentration. The results also reveal strong indications of strain-aging. Examination of similar specimens during tests at room-temperature (as in Section 15) revealed that fractures originated in the weld even in the absence of reinforcement.

It is concluded, therefore, that the origin of fracture at the weld is promoted not only by the geometry of the standard specimen but by the properties of the weld itself. It appears also that the strain-aging tendency is dependent upon the presence of the weld.

## 21. THE COOLING RATE FOLLOWING WELDING

It is important to recognize that, as a result of the procedure employed in the present work, the cooling rate of the weld may not have been typical of the rates commonly encountered in practice in plate of comparable thickness. The difference arises from the fact that the volume of a laboratory specimen (¾ x 4 x 9 in. in the present instance) is necessarily smaller than that of most plate structures. Soon after welding, the temperature of the specimen approaches a more or less uniformly distributed value considerably higher than room temperature. In a small specimen this leveling-off temperature, dependent on the ratio of total heat input to volume, is considerably higher than in a heavy weldment. Accordingly, the small specimen cools more slowly as it approaches room temperature.

It is of interest, then, to ask the following question: What might be the consequences, in terms of strain-aging, if the weld were caused to cool more rapidly than in the present investigation?

If the strain-aging indications are produced by a precipitation mechanism, the degree of supersaturation of the weld after cooling is presumably a factor of importance. Slow cooling facilitates precipitation at moderately elevated temperatures. (Such precipitation need not itself reduce ductility since the dispersion might be of a harmless nature.) The degree of supersaturation retained at room temperature would thus be minimized by slow cooling and susceptibility to strain aging might be reduced.

On the other hand, an increase in the rate of cooling would be expected to increase the degree of supersaturation at room temperature. Rapid cooling might thus produce a condition more susceptible to strain-aging. This possibility, not studied in the present work, deserves investigation.

Figure 22 describes the cooling history prevailing in the present work. It is based on autographic records derived from thermocouples at the mid-length of the weld. The couples were inserted in the molten metal during welding. It may be seen that the cooling of the weld was very slow after a leveling-off temperature of about 350° F. has been attained.

## 22. SOME PRACTICAL IMPLICATIONS

Strain-aging effects having been noted in the laboratory, it is of interest to consider some of their practical implications. Since the results of notched-bend tests at −40° F. are difficult to correlate with service requirements (as is the case regardless of the method employed to measure ductility), it is proposed in this section only to present some comments of a rather general nature.

Actually, most welds are not subjected to appreciable plastic deformation aside from the small amount induced by differential cooling. The latter, equivalent to less than ½% elongation, would appear to be of little concern. Under the conditions of this investigation, a bend angle of 1° has been found to induce an elongation of about 5% at the base of the notch. An elongation of ½% thus corresponds to a bend angle very much smaller than 1°.

Referring now to applications in which effective prestraining is unavoidably encountered in practice, the following findings and comments may be useful in cases where it is desired to minimize the strain-aging hazard:

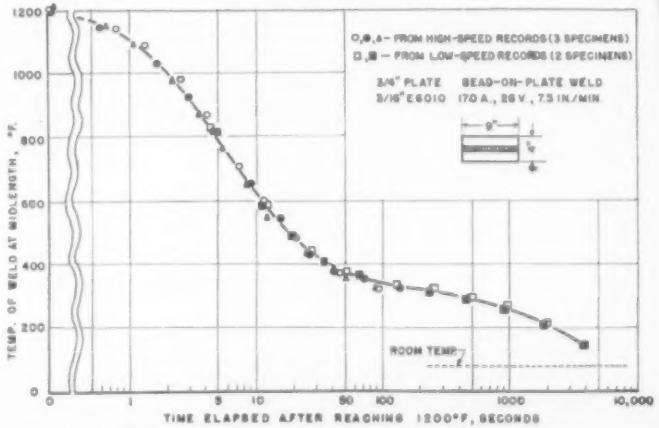



*Fig. 22 Cooling history of the weld in standard specimen*

1. On the basis of Sections 11, 12, 13 and 19, it seems improbable that immunity to strain-aging can be achieved through selection of electrodes or plate materials from among the varieties in common use.

2. It appears from Section 9 that embrittlement may be expected to pass its peak within a week after prestraining if storage is at room temperature. This suggests that difficulty need not be expected after long periods of storage.

3. From Section 10, it appears that strain-aging is most severe when prestraining is done soon after welding. Again a long period of storage may be expected to be beneficial.

4. According to Section 18, storage of the weld at an elevated temperature greatly accelerates the benefits of prolonged storage at room temperature. For this reason the usual thermal stress-relieving treatment would be expected to minimize strain-aging hazards even in the case of severely prestrained welds.

5. As noted in Section 21, welds in practice often cool more rapidly than do laboratory specimens. Thus, it is possible that there may occur strain-aging effects of greater intensity than those indicated in this investigation.

## 23. SUMMARY AND CONCLUSIONS

The strain-aging characteristics of E6010 welds on A285 plate have been investigated, using the bead-on-plate notched-bend test at −40° F. for the evaluation of ductility. Among the factors investigated are the degree of prestraining, the duration of aging both before and after prestraining, the aging temperature and the temperature of the test to fracture.

In addition to the work with E6010 welds on A285 plate, other electrodes and other plate materials were employed in supplementary tests.

The principal findings and accomplishments of the investigation may be summarized as follows:

1. Under the conditions employed, susceptibility to strain-aging appears to be generally characteristic of arc welds on mild steel.

2. Welds on a fully killed steel (A.S.T.M. A201) were no less susceptible than those on semikilled A285 and on the rimmed "E" steel of the Navy series.

3. With regard to strain-aging, the behavior of low-hydrogen E6016 welds is similar to that of the high-hydrogen E6010, E6012 and E6020 types.

4. Under the conditions employed, the peak of strain-age embrittlement is attained at room temperature within a week after prestraining. Less than one month suffices to effect a full restoration of ductility.

5. Aging at 212° F. greatly accelerates the attainment of the strain-aging peak and the subsequent restoration of ductility.

6. An increasing period of storage before prestraining causes a decrease in the severity of subsequent strain-aging.

7. The strain-aging effect is believed to reside in the weld metal itself rather than in the heat-affected zone or in the parent plate.

8. Some practical implications of the findings have been discussed.

9. Since, in practice, welds often cool more rapidly than the laboratory specimens of this investigation, it seems possible that the former may exhibit strain-aging effects of greater severity. It is recommended that this possibility be investigated.

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Sure they'll crack and break if you *can* hit them hard and often enough, or drop them from some dizzy height. After all they are not indestructible. They can't be. Nothing is.

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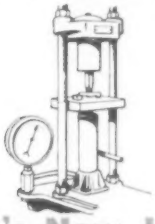

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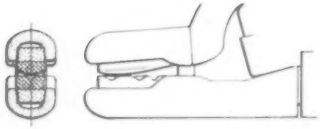

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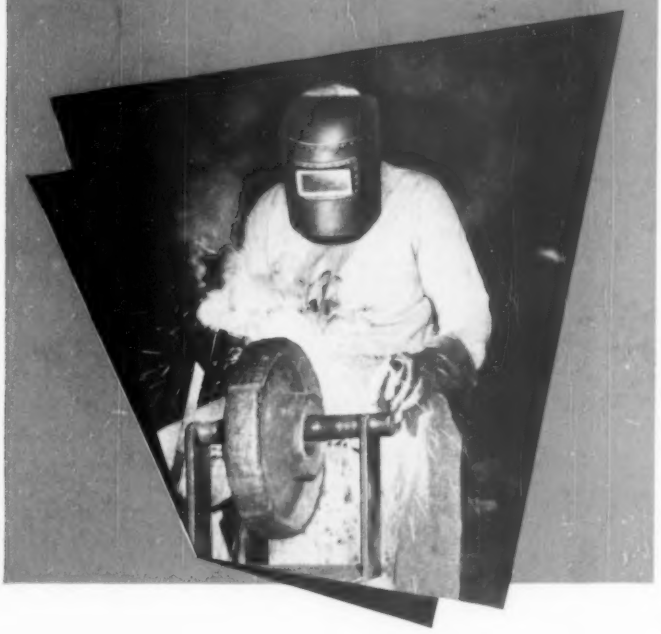

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